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NAVAL POSTGRADUATE SCHOOL

Monterey, California



THESIS

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AN EVALUATION OF THE PROPOSED
MSRT REPLENISHMENT MODEL FOR
WHOLESALE CONSUMABLE ITEMS

by

Richard E. Bojke
and
Timothy H. Stringer

December 1989

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This thesis compares the current wholesale level consumable replenishment inventory model, now in use at Navy Inventory Control Points (ICPs), with a proposed Mean Supply Response Time (MSRT) Model. The purpose of the MSRT model is to introduce a readiness measure into wholesale inventory management. The objective of the MSRT model is to determine inventory depths which minimize the mean supply response time subject to not exceeding the inventory dollar investment provided by the UICP model for the same items. The MSRT model uses a marginal analysis optimization procedure. A comparative analysis of the models' results indicates that the MSRT model provides consistently better supply system performance, in terms of supply material availability (SMA) and mean supply response time (in days), than the UICP model for items with a medium to low average quarterly demand. For medium to high quarterly demand items, there is no significant difference in the models' performances.

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MSRT REPLENISHMENT MODEL FOR
WHOLESALE CONSUMABLE ITEMS

by

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NAVAL POSTGRADUATE SCHOOL
December 1989

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I. INTRODUCTION

This chapter addresses the following issues:

1. The motivation behind the research.
2. The objectives of the research.
3. A preview of subsequent chapters.

A. MOTIVATION

Since 1982 the Naval Postgraduate School (NPS) has been examining in depth the inventory control models in use at the Navy's Inventory Control Points (ICP). The two main ICP's are the Ships Parts Control Center (SPCC) and the Aviation Supply Office (ASO).

This work was undertaken at the request of the Naval Supply Systems Command (NAVSUP) in conjunction with NAVSUP's Resolicitation Resystemization Project. The primary objective of the resolicitation project was the acquisition of new computer hardware for the ICP's, but the effort also provided the opportunity to make software improvements that would make better use of the new hardware.

Initially, NAVSUP asked NPS to "develop improvements to the existing peacetime wholesale provisioning models for secondary items used by ... SPCC and ... ASO." [Ref. 1: pp. 1] Provisioning models are those that determine the range and depth of repairable and consumable items that should be initially procured in support of a new weapon system. A provisioning model's objective is to procure enough spares to provide adequate support for the weapon system until the first wholesale replenishment order arrives.

In response to NAVSUP's initial request, NPS proposed several provisioning models [Ref. 1] and conducted detailed comparisons between these models and those being used by the ICPs at that time. [Ref. 2] As a result of these analyses a new provisioning model was adopted at the ICP's in 1984. This model is called the Mean Supply Response Time (MSRT) model because its objective is to minimize the MSRT for a set of secondary items belonging to a new weapon system. Mean supply response time is defined as the mean time it takes the supply system to satisfy the demand for an item.

The logical next step was to develop a replenishment model having the same objective function. This model would be used to make all subsequent buys of inventory after

the initial provisioning buy. The initial effort in this direction concentrated on a repairable replenishment model.

The initial attempt to extend the MSRT concept to repairable item management was described by Gormly in his master's thesis at NPS. [Ref. 3] His thesis investigates an aggregate demand inventory model for repairable items that assumes:

the probability distribution for the inventory position (defined as on-hand plus on-order plus in-repair minus backorders) was ... uniform with its equally likely states being a function of a weighted sum of the procurement quantity Q_p and the repair batch induction quantity Q_i . [Ref. 4: pp. 3]

This average was then incorporated into the continuous review model of Hadley and Whitin, [Ref. 4: chap. 4]. A different approach was taken by Apple, also for his master's thesis at NPS. [Ref. 5] The model presented by Apple took a queuing model approach towards evaluating the delay created by waiting for carcasses to accumulate for repair, and attritions (not repairable) to "accumulate" towards a procurement quantity. The model was actually a provisioning rather than a replenishment model.

In the spring of 1987, McMasters attempted to prove the inventory position probability distribution assumed in Gormly's thesis. He discovered that the probability distribution assumption was incorrect. He also found that the P_{our} repairable model developed by Fleet Material Support Office (FMSO) had been based in the same assumption and hence was also incorrect. McMasters was able to develop a correct version of the probability distribution for the case of a repair survival rate of 100% (all carcasses inducted for repair will be successfully repaired). Research continues on the case of a repair survival rate less than 100%.

Fortunately, the problems with the probability distribution of the inventory position do not exist if only consumable items are considered. The inventory position distribution is merely that of the exact formulation from Hadley and Whitin. [Ref. 4: chap 4] The consumable version of the MSRT model is also a limiting case of the repairable model. As a consequence, it is convenient to conduct a comparison between the consumable version of the MSRT model and the current UICP inventory model rather than waiting until the MSRT repairable model is completely developed. Such a comparison will provide insights into the benefits of the MSRT model and possibly result in its implementation for consumables rather than waiting for the repairable version.

B. THESIS OBJECTIVES

1. Develop a computer program for the current ICP model for the inventory management of consumable items.
2. Derive an MSRT model for consumable items and develop a computer program for it.
3. Using ICP provided inventory management data, make a comparative evaluation of the performances of the proposed MSRT model and the current ICP model.

C. PREVIEW OF SUBSEQUENT CHAPTERS

In chapter II a discussion of the Navy Supply System is provided to give the reader an understanding of the environment in which the models are designed to operate. This is followed by an in-depth look at the current ICP model, including the mathematical formulas and the constraints that are applied. In chapter III the MSRT model is presented and the algorithm used for optimization is described. Chapter IV discusses the data, hardware and software used in the research. Chapter V presents the measures of effectiveness used to assess model performance, the results of the comparative analysis and an evaluation of these results. Chapter VI provides a brief summary and recommendations.

II. THE NAVY SUPPLY SYSTEM AND THE UICP CONSUMABLE INVENTORY MODEL

The intent of this chapter is to introduce the reader to the supply system in which the two inventory models that form the crux of this research are designed to operate. The chapter also explains how the UICP model functions within that system. This will be accomplished by:

1. Giving an overview of the Navy Supply System.
2. Describing the wholesale consumable inventory system.
3. Explaining basic inventory theory.
4. Deriving the equations used in the UICP model.
5. Discussing the constraints placed on the UICP model.

A. NAVY SUPPLY SYSTEM

The purpose of this section is to identify the structure to which the Navy Supply System belongs and the components which make up the Navy Supply System.

The Naval Supply Systems Command (NAVSUP) is responsible for the management of the Navy Supply System. The Commander of NAVSUP gives policy direction and guidance on inventory management of all material within the system. The actual wholesale supply system management functions are carried out by inventory control points (ICPs). The major Navy ICPs are the Aviation Supply Office (ASO) for aviation material and the Ships Parts Control Center (SPCC) for surface ship and submarine items.

The ICPs provide two broad categories of support: program support and supply support. While both categories are equally vital to the success of the Navy Supply System, the supply support category is of most importance to this thesis. Supply support functions include:

1. Budget development for parts support.
2. Requirements determination.
3. Material procurement.
4. Integrated inventory management.
5. Material distribution and issue.
6. Repairables management.

This thesis will concentrate on the functions of requirements determination and budget development for parts support.

The Navy stock points are the holders of the inventories in the Navy Supply System. "The main mission of a stock point is the physical distribution of material." [Ref. 6: pp. 26] Their functions include:

1. Receiving and stowing material.
2. Issuing and shipping material.
3. Reporting receipts and issues to each item's ICP.

Stock points are located throughout the United States and overseas, near major concentrations of operational and industrial customers.

The two types of material managed by the Navy Supply System are repairables and consumables. "A repairable is an item of supply that can be made to function by a repair process after it breaks." [Ref. 6: pp. 4] Examples of repairables include gear boxes and circuit boards. A consumable is an item which, when broken, during use, is not repaired. Examples of consumables are valves, steam pipe and flanges. The inventory models involved in this thesis research deal only with consumables.

The Navy groups similar items for administrative and management purposes into Cognizance Groups (COG), which are designated by two alphanumeric symbols or "digits". The COG is used to identify the ICP or agency responsible for managing the item. It also indicates whether the item is a repairable or consumable. The consumable items used in this research have a "COG" of 1H, indicating that the items are consumables managed by SPCC.

To foster inventory management and flexibility, COGS are further divided by adding two more digits to them. These last two digits segregate items by essentiality or weapon system and by requisition frequency. For example, the 4-digit cog, 1H4A represents a 1H cog item having an essentiality of 4 (the highest) and a requisition frequency of 3 or more per quarter (denoted by the A).

B. WHOLESALE CONSUMABLE INVENTORY SYSTEM

Within the Navy Supply System there are three levels of inventory management of items:

Wholesale - The inventory is managed by ICP inventory managers. The inventory managers have worldwide visibility and control of this inventory.

Retail Intermediate - This level of inventory is designated to support a specific geographic area and is normally managed by the Navy stock point in that geographic area.

Retail Consumer - This is a level of inventory held for an activity's own use.

The inventory models in this research deal only with the wholesale inventory level.

The general characteristics of wholesale level inventories are:

1. Inventory levels are computed based on system-wide demand data.
2. The ICP inventory manager knows where the material is located and has unrestricted access to it.
3. The ICP must approve all requisitions for items from these inventories.
4. Material is assigned to one or more retail stock points for storage and issue by the ICP inventory manager.

As stated in item 1 above, wholesale inventory levels are computed based on system-wide demand data. How does this demand data reach the ICP inventory manager? It is the responsibility of the stockpoints to submit the demand data to the ICPs. When a stock point issues a consumable to an end-use customer, the stock point reports the issue to the cognizant ICP via a transaction item report (TIR). Stock points also use TIRs to report receipt and redistribution of material. The information from the TIRs is immediately processed into the ICP data files. This and other information in the files aids the ICP inventory manager in making decisions involving requirements determination, material distribution and procurement of replenishment stock. Data from these files was used in the comparative evaluation of the current UICP and proposed MSRT inventory models.

C. THE BASIS FOR THE ICP INVENTORY MODEL

There are two major questions an ICP inventory manager must answer with regard to consumable items:

1. How much to order; i.e., the **reorder quantity (Q)**?
2. When to order; i.e., the **reorder point (R)**?

In an unconstrained world the ICP inventory manager could order as much as the customer needed and order as frequently as demands occurred. Unfortunately, the real world is full of constraints with which the inventory manager must deal. These include **inventory costs**.

The variable inventory costs which are dependent on **Q** and **R** are generally divided into three categories:

Order Costs - costs accrued when determining and processing buys, and the stockpoints' receipt and stowage costs.

Holding Costs - includes costs of investment, storage, obsolescence and pilferage.

Shortage Costs - costs of not having items when needed. ✓

These three costs plus the cost of buying the items (which is not dependent on **Q** and **R**) make up the total inventory costs.

Two basic types of inventory models exist which consider these inventory costs when computing reorder quantity, **Q** and reorder point, **R**. They are the continuous review and periodic review models. The consumable model used by the Navy ICPs for whole-sale inventory is a type of continuous review model called the min-max model. The min-max model seeks the values of **Q** and **R** which minimize the average annual variable inventory costs.

In the min-max model, a replenishment order occurs when an item's inventory position (on-hand plus on-order minus backorders) hits or falls below **R**. At the time of ordering, the amount ordered is **Q** plus the difference between the reorder point value and the inventory position value at that time. In the simplest form of the min-max model, **Q** is usually the amount which minimizes the average annual ordering and holding costs. For consumables, this is the Wilson-Harris economic order quantity [Ref. 7]: ✓

$$Q = \sqrt{\frac{SAD}{IC}};$$

where:

A = administrative order cost;

D = forecasted average quarterly demand;

I = holding cost rate; and

C = cost of one unit of the item.

The reorder point, **R**, for the simplest form of the min-max model is determined from minimizing the costs of carrying safety stock and incurring backorders (shortages). It is a function of leadtime demand and the variability of demand. The formula for **R** is:

$$R = (D \times L) + SL;$$

where:

L = the forecasted mean procurement lead time in quarters; and

SL = safety level, a function of demand and lead time variability.

The reorder point is computed by first computing the optimal risk of a stockout according to the following formula [Ref. 7: pp. 145] :

$$RISK = \frac{QIC}{QIC + 4\lambda D};$$

where:

λ = shortage cost of one demand backordered for one year.

The optimal risk is used with the probability distribution for demand during procurement leadtime to derive the actual reorder point value. This reorder point value is the mean leadtime demand ($D \times L$ which is designated by μ), plus the safety level. For the normal distribution, the safety level is

$$SL = z \times \sigma;$$

where:

z = the standard normal deviate for the optimal risk; and

σ = the standard deviation of leadtime demand.

How else is the performance of an inventory model judged besides by the minimization of average annual variable costs? Typically, several other Measures of Effectiveness (MOEs) are used. A MOE is a function of the decision variables (in this case Q and R) and inventory system parameters. The two major MOEs the Navy Supply System uses are:

1. How well the available Navy Stock Fund (NSF) budget is allocated (another cost type MOE).
2. Supply material availability (SMA)(customer service type of MOE).

In this era of diminishing resource dollars, the Navy Supply System must allocate its NSF inventory investment dollars to maximize customer support. The UICP model does this by allocating these investment dollars to the optimal order quantities and reorder point which minimize total average annual inventory costs while attempting to achieve a minimum goal of 85% SMA. The dollar investment needed to support the inventory depth (order quantity + reorder point) is used by NAVSUP in formulating NSF budget requirements.

D. THE UICP WHOLESALE CONSUMABLE INVENTORY MODEL

In this section, the inventory model used by the ICPs to compute the reorder quantity, Q , and the reorder point, R , for consumables will be discussed. The following topics will be covered:

1. Total variable cost equation.
2. Model assumptions.
3. Derivations of Q and R .
4. Constraints.

1. Total Variable Cost Equation

The Department of Defense (DOD) provides policies for determining inventory levels in DOD Instruction 4140.39 and states that the objective is "to minimize the total of variable order and holding costs subject to a constraint on time-weighted, essentiality-weighted requisitions short." [Ref. 6: pp. 2]

The total variable cost (TVC) equation in DOD Instruction 4140.39 looks like:

$$TVC = \text{Order Cost} + \text{Inventory Holding Cost} + \text{Shortage Cost}$$

The order cost, inventory holding cost and shortage cost are functions of Q and R .

The UICP model, based on DOD Instruction 4140.39 is the minimization of an annual variable cost equation composed of the sum of three terms:

Ordering Cost - an average number of orders per year times the administrative cost of placing an order or contract.

Holding Cost - average number of units of stock on hand at any random point in time, times the cost to hold one unit of stock in inventory for a year.

Shortage Cost - average number of requisitions on backorder at any random point in time, times the cost of not filling one requisition for a year times the military essentiality of the item. [Ref. 6: pp. 3-A-3]

The total annual variable cost (TVC) equation is:

$$TVC = \sum_{i=1}^n \left(\frac{4D_i}{Q_i} \right) A_i + \sum_{i=1}^n IC_i \left(R_i + \frac{Q_i}{2} - \mu_i + B_i(Q_i, R_i) \right) + \lambda \sum_{i=1}^N \frac{E_i}{S_i} B_i(Q_i, R_i)$$

where:

i = item index;

n = total number of items in a inventory;

B = expected number of units of item i backordered at any random point in time;

λ = shortage cost of one requisition backordered for one year;

E = military essentiality of item i ; and

S = expected number of units per requisition for item i .

From reference 6 the formula for $B_i(Q_i, R_i)$ is:

$$B_i(Q_i, R_i) = \frac{1}{Q_i} \int_{R_i}^{\infty} (x - R_i) [F_i(x + Q_i \mu_i) - F_i(x; \mu_i)] dx;$$

where:

$F_i(\cdot)$ = cumulative probability distribution of leadtime demand.

2. Model Assumptions

The ICPs use the following key simplifying assumptions in the UICP consumables inventory model. While these assumptions may not reflect the "real world" environment in which the inventory model operates, the assumptions are necessary to streamline and simplify the computation of Q and R . The assumptions are:

1. Steady state demand environment exists (the demand distribution does not change over time).
2. Infinite procurement quantities are possible.
3. Continual review of the inventory position occurs.
4. The quantity is sufficient to increase the inventory position up to a value of $Q + R$.
5. Procurement cost, A , is a constant, independent of order quantity, Q .
6. Demands and other model parameters associated with different items are independent.

3. Derivations of Q and R

a. Derivation of Order Quantity (Q)

The derivation presented in this section was taken from reference 8. The optimal order quantity, Q , is determined by solving:

$$\frac{\partial TVC}{\partial Q} = -\frac{4AD}{Q^2} + \frac{IC}{2} + \frac{\partial B(Q,R)}{\partial Q} \left(IC + \frac{\lambda E}{S} \right) = 0;$$

where:

$$\frac{\partial B(Q,R)}{\partial Q} = \frac{\partial}{\partial Q} \frac{1}{Q} \int_R^\infty (x-R)\{F(x+Q; \mu) - F(x; \mu)\}dx.$$

However, this is an equation involving an implicit function of Q and it is difficult to solve explicitly. It can be solved iteratively, but those calculations would be tedious for large inventory systems containing a large number of items. For this reason, the ICP's ignore this term in $\frac{\partial TVC}{\partial Q} = 0$ and solve for Q using the remaining terms. The result is

$$Q_{EOQ} = \sqrt{\frac{SDA}{IC}}.$$

b. Derivation of Reorder Point (R)

The optimal reorder point, R , is determined from

$$\frac{\partial TVC}{\partial R} = IC + \left(IC + \frac{\lambda E}{S} \frac{\partial B(Q,R)}{\partial R} \right) = 0.$$

Limiting arguments to eliminate Q from this formula results in an optimal R satisfying

$$RISK = 1 - F(R; \mu) = \frac{SIC}{SIC + \lambda WE};$$

where:

W = expected requisitions per quarter.

4. Constraints

The UICP consumable inventory model imposes several constraints on the optimal Q and R from the total variable cost equations. These constraints are imposed because many "real world" factors cannot be included in the cost equations. These constraints will be discussed in this section.

a. Reorder Quantity Constraints

The ICP's impose constraints on the quantity they actually order so that their order quantity, \hat{Q} , is determined from the following formula:

$$\hat{Q} = \text{minimum}\{12D, \text{maximum}(Q_{EOQ}, 1, D)\}.$$

This formula insures that:

1. The reorder quantity is at least 1.

2. An item is reordered no more than once per quarter (by ordering at least D , the quarterly demand).
3. The maximum size of an order is no more than 3 years' demand ($12D$) per DODINST 4140.39.

b. Reorder Point Constraints

The reorder point is constrained in two steps. First, the right hand side of the RISK formula is computed. That RISK value is then constrained to a value of no less than an ICP-set minimum risk and no greater than an ICP-set maximum risk. These risk limits are established to prevent under or over investment in any given item.

The reorder point, R^* , for the constrained risk is computed next. The distribution used for any item is dependent upon the demand characteristics of that item. UICP limits the choices of distributions to the normal, Poisson and negative binomial. The choice is based on a comparison of μ , where $\mu = D \times L$, to an ICP-set parameter, called the probability breakpoint. If μ is less than the probability breakpoint a negative binomial probability distribution is used. If μ is greater than or equal to the probability breakpoint a normal probability distribution is selected. A Poisson probability distribution is used for very low-demand items, specially designated by a "Mark Code of 0".

The reorder point, R^* , is then further constrained to no less than zero or an ICP-set value, called the Numeric Stockage Objective (NSO is a minimum stockage level established by an ICP on low demand items for insurance stockage purposes), no less than an ICP-set percentage of μ or the number of wholesale stockpoints carrying the wholesale level for the item (called policy receivers) designated by the ICP, and no larger than an ICP-set percentage of μ with on-hand assets not exceeding the shelf life quantity. The result is the final constrained reorder point, \hat{R} .

5. Selection of λ

The shortage parameter, λ , is chosen so that the resulting inventory levels meet the SMA goal of 85%. Later it is reduced if sufficient funds are not made available (not a current problem under stock funding).

III. MEAN SUPPLY RESPONSE TIME MODEL

This chapter explains both the theory and the computational procedures used in the mean supply response time (MSRT) wholesale consumable inventory model.

A. THE MSRT MODEL

In the MSRT model the objective is to determine the depth of each item which minimizes the aggregate mean supply response time over all items within a given four-digit cog, subject to a budget constraint or maximum investment level for that four-digit cog. (As stated in chapter I, the mean supply response time is defined as the mean time it takes the supply system to satisfy the demand for an item.)

Mathematically the MSRT model seeks the optimal maximum integer depths, $SW_i \geq 0$ ($i = 1, 2, \dots, n$), which minimize:

$$MSRT = \frac{\sum_{i=1}^n D_i \times MSRT_i(SW_i)}{\sum_{i=1}^n D_i};$$

subject to:

$$\sum_{i=1}^n C_i \times SW_i \leq Investment\ Level;$$

where:

i = item index;

D = forecasted average quarterly demand for item i ;

SW = the depth of item i ; and

C = unit price of item i .

It has been shown [Ref. 1] that:

$$MSRT_i = \frac{TWUS_i}{D_i};$$

where TWUS stands for the expected time-weighted units short per year. It is defined [Ref. 4: pp. 185] as:

$$TWUS_i(SW_i) = (\mu_i - SW_i) + \sum_{x_i=1}^{SW_i} (SW_i - x_i) \times p_i(x_i; \mu_i);$$

where $p(x; \mu)$ is the Poisson or negative binomial probability mass function for demand x during lead time and $\mu = D \times L$. If demand can be approximated by the normal distribution then the value of $p(x; \mu)$ for integer x values can be obtained by using a continuity correction on the normal. Therefore, the objective function can be rewritten as:

$$MSRT = \frac{\sum_{i=1}^n TWUS_i(SW_i)}{\sum_{i=1}^n D_i}$$

and, because the denominator is a constant, the objective function reduces to:

$$\sum_{i=1}^n TWUS_i(SW_i).$$

Conceptually, time-weighted units short for an item are the number of demands that can't be satisfied by issues from stock, weighted by the length of time that each demand remains unsatisfied (in a backorder position). In the case of consumables these demands normally remain backordered until a procurement arrives.

The constraint in the MSRT model has been established, for comparison purposes, as the total investment level resulting from the UICP model for the same four-digit cog. That value is obtained by adding the \hat{Q}_i and \hat{R}_i values to get the maximum UICP depth for each item, multiplying this depth by the unit cost C_i , and summing these products over all i , $i = 1, 2, \dots, n$.

B. MSRT MODEL SOLUTION

The optimization technique used on the MSRT model is marginal analysis because of the integer nature of demand and hence the depth SW . Basic to the marginal analysis approach is the ratio RR_i , where:

$$RR_i = \frac{TWUS_i(X-1) - TWUS_i(X)}{C_i}.$$

This represents the ratio of the improvement in $TWUS_i$, when the depth of item i is increased from $X-1$ to X , to the cost C_i incurred when the depth is increased by that one unit.

To compute an optimal depth for the MSRT model using marginal analysis, all items are initialized with a depth of zero ($SW=0$) and RR is computed for $X=1$ for all i . That item having the largest value of RR_i is then increased by one in its depth (SW). Its RR value is next computed with $X=2$ and all RR_i values are compared again. That item whose RR is largest has its SW increased by one unit, its X value is increased by one, and a new RR value is computed for it. After each unit increase in an item i , the left-hand side of the investment constraint is increased by C_i . This procedure of comparing RR_i values, increasing one item's depth and reducing the budget constraint is repeated until the addition of the next unit would cause the cumulative investment level for the items within that four-digit cog to exceed the investment level the UICP model produced for the same four-digit cog. At this point the calculations are terminated. The calculations could be continued, however, for only those items whose unit prices remain low enough not to exceed the budget constraint on the next step.

Each time an item goes through the procedure of computing the improvement brought about by adding one unit to its depth, its mean supply response time in days is also computed using the following formula:

$$MSRT_i = \frac{91 \times TWUS_i(SW_i)}{D_i}.$$

If the item's $MSRT$ is less than 0.01 it is excluded from further depth increases. This value was set as a lower bound on any item's $MSRT$ since further reductions would not significantly enhance system performance. The value of 0.01 is, however, arbitrary.

As mentioned earlier, to produce an optimal depth, SW , using the $MSRT$ model the depth of each item needs to be initialized at zero. If initialized at zero the model produced a depth of zero for many low demand items used in the comparative analyses. Although this is correct, depths of zero are rarely allowed in the UICP model. In the UICP model the $\hat{Q} + \hat{R}$ depth is almost always one or greater because the order quantity is almost always constrained to be one and the reorder point is constrained to no less than zero. Despite the constraints in the UICP model for very slow movers this is not

an accurate representation of the way these items are actually managed. Usually these items have no material on-hand and no material on-order until a requisition is received. The true reorder point then is -1, the reorder quantity is 1 and the $\hat{Q} + \hat{R}$ depth is zero.

In this research effort the MSRT model was run under three different conditions: depth initialized at zero; depth initialized at one; and depth initialized at the UICP computed reorder point. With the depth initialized at one the results may not be optimal, but they provide a basis for a comparison with the existing UICP model.

The MSRT model was run with the depth initialized at the reorder point computed by the UICP model to assess the impact on the different measures of effectiveness and computer run times of never having a depths less than the UICP reorder points computed by UICP.

IV. SOFTWARE, HARDWARE AND DATA

This chapter describes the data that was used to run the models and the computer hardware and software utilized.

A. SOFTWARE AND HARDWARE

The original programming of the MSRT model was done in FORTRAN 66 by Professor Alan McMasters. The first step in this thesis research was to convert the original programming to WATFOR 77. The conversion was made to allow for easier program formulation, analysis (debugging) and structuring. The completed program is in WATFOR 77 Release 2.5. The operating system was VM CMS. The hardware on which the programming and running of the models was done was the IBM 3033 model mainframe at the W.R. Church Computer Center at the Naval Postgraduate School, Monterey, California.

B. DATA

The data that was used for the comparative analyses was from a tape containing the data for all the IH cog National Item Identification Numbers (NIINs) on file at SPCC in the spring of 1985. The tape contained 113,647 IH records with each record providing information on one NIIN. The records were in the CARES (Computation and Research Evaluation System) format.

Because of the program size and the limitation on virtual storage and CPU time available for this research, only select data was used. Computer runs were restricted to one hour of CPU time due to policies of the NPS Computer Center. Data samples were therefore selectively restricted in size to enable program processing within the one hour time limit. Data samples were also restricted in size because of the large number of arrays used in the program and the limited virtual storage available to an individual user.

The process used for selecting data was to first compute the average quarterly demand for all items within each four-digit cog. Next, enough four-digit cogs were selected to represent the entire range of average quarterly demands. Finally, if all the NIINs within a given four-digit cog couldn't be processed through the models within time and space limitations, a subset of those items was selected which had an average demand closely approximating that of the four-digit cog's entire population.

Table 1 is a breakdown of the entire IH data set and information on the data sets that were used for the comparisons. The first entry in Table 1 shows the items from the data that were not assigned a four-digit cog.

Table 1. BREAKDOWN BY 4-DIGIT COG OF THE DATA BASE

COG	TOTAL NUMBER OF ITEMS	AVERAGE QUARTERLY DEMAND	SAMPLE SIZE	SAMPLE AVERAGE QUAR- TERLY DE- MAND
IH	1566	0.81		
IHN1	1026	325.52		
IHN2	1893	25.89		
IHN3	13941	1.25		
IHN4	1	0.40		
IHS1	282	86.16	281	86.16
IHS2	1021	21.90		
IHS3	9905	1.13		
IHS4	7	2.43		
IHOA	568	526.71	100	511.46
IHOB	983	22.37		
IHOC	11700	74.42		
IHOD	11	4567.95	11	4567.95
IHOE	13	3.55		
IHOF	144	0.88		
IHI1A	818	232.50		
IHI1B	2005	12.87		
IHI1C	18900	0.94		
IHI1D	71	41.13		
IHI1E	174	11.18		
IHI1F	2037	0.39	1420	0.40
IH2A	582	157.66	100	140.91
IH2B	1091	25.00	492	24.17
IH2C	4711	1.43		
IH2D	79	236.03	79	236.03
IH2E	132	49.07		
IH2F	613	4.02		
IH3A	1851	71.16		
IH3B	3150	11.08		
IH3C	18952	1.28		
IH3D	457	78.55		
IH3E	583	8.57	583	8.57
IH3F	3141	1.69		
IH4A	1592	98.23		
IH4B	1669	5.73		
IH4C	6733	0.62		
IH4D	173	167.26		
IH4E	190	5.61		
IH4F	882	0.84	882	0.84

V. MEASURES OF EFFECTIVENESS

This chapter discusses the Measures of Effectiveness (MOEs) used in the comparative evaluation and gives the computer results for each. The following is a list of MOEs used:

1. Mean Supply Response Time (MSRT).
2. Supply Material Availability (SMA).
3. Average Days Delay (ADD).
4. Average Days Delay for Backordered Requisitions (ADDBO).
5. Days Of Safety Level (DOSL).
6. CPU Run Time.
7. Depth Churn.

SMA (specifically SMA2), ADD and ADDBO are standard CARES (Computation and Research Evaluation System) MOEs [Ref. 9].

A. MEAN SUPPLY RESPONSE TIME (MSRT)

Mean Supply Response Time is the mean time in days taken by the supply system to respond to the demand for an item. The aggregate MSRT for each four-digit cog is computed as follows:

$$MSRT = \left[\frac{\sum_{i=1}^n [91 \times TWUS_i]}{\sum_{i=1}^n D_i} \right];$$

where:

- TWUS = Time-weighted units short in days for item i ;
- D = Forecasted average quarterly demand for item i ; and
- n = Number of items in the four-digit cog.

Table 2 gives the results for the MSRT measurements for the MSRT and UICP models with the MSRT model depth initialized (ID) at zero, one and the UICP reorder point.

Table 2. MODEL COMPARISONS FOR MSRT (IN DAYS)

COG	SAMPLE AVERAGE QUARTERLY DEMAND	UICP MODEL	MSRT MODEL ID = 0	MSRT MODEL ID = 1	MSRT MODEL ID = \hat{R}
1H0D	4567.95	1.384	0.394	0.401	0.606
1H0A	511.46	1.659	0.369	0.369	0.403
1H2D	236.03	1.189	0.653	0.653	0.671
1H2A	140.91	1.920	1.221	1.221	1.242
1HS1	86.16	1.096	0.491	0.491	0.531
1H2B	24.17	4.192	1.824	1.852	2.217
1H3E	8.57	12.958	4.209	4.219	4.749
1H4F	0.84	36.871	3.412	5.510	6.877
1H1F	0.40	24.738	0.027	0.455	0.496

1. MSRT Analysis and Observations

As would be expected, given its objective function of minimizing mean supply response time, the MSRT model provides better mean supply response time than the UICP model in all cases. The improvement in performance becomes greater as the average demand of the population decreases.

The MSRT model with depth initialized at zero provides the best results, but the difference in performance between the three forms of the MSRT model is negligible until the average quarterly demand of the sample gets very small.

B. SUPPLY MATERIAL AVAILABILITY (SMA)

Supply Material Availability is the percent of all requisitions that are satisfied from on-hand stock over a year. The Chief of Naval Operations has set the current SMA goal at 85%. For purposes of this research SMA is computed two different ways, called SMA1 and SMA2. SMA¹ is a demand-based measure calculated as one minus the expected number of backorders divided by the average quarterly demand. SMA2 is a requisition-based measure calculated as one minus the number of requisitions short per year divided by the average annual requisition frequency. The formulas for each are as follows:

$$SMA1 = 1 - \left[\frac{\sum_{i=1}^n [EBO_i]}{4 \times \sum_{i=1}^n D_i} \right];$$

$$SMA2 = 1 - \left[\frac{\sum_{i=1}^n [RSPY_i]}{4 \times \sum_{i=1}^n [W_i]} \right];$$

where:

EBO = Expected number of backorders per year;

RSPY = Requisitions short per year; and

W = Quarterly requisition frequency.

Tables 3, 4, and 5 present the results for these two SMA MOEs for the MSRT model, with the depth for each item initialized at 0, 1 and the reorder point (RP), respectively.

**Table 3. MODEL COMPARISON FOR SMA WITH THE MSRT MODEL
HAVING ID = 0**

COG	SAMPLE AVG. DEMAND	UICP SMA1	MSRT SMA1	UICP SMA2	MSRT SMA2
1H0D	4567.95	99.98	99.98	92.75	87.38
1H0A	511.46	99.86	99.87	97.67	96.92
1H2D	236.03	99.73	99.79	94.60	95.51
1H2A	140.91	99.54	99.61	94.40	94.86
1HS1	86.16	99.47	99.69	96.40	97.40
1H2B	24.17	98.62	99.32	88.90	92.75
1H3E	8.57	97.54	98.62	91.95	94.37
1H4F	0.84	93.30	99.31	86.56	98.74
1H1F	0.40	84.35	99.66	84.36	99.03

Table 4. MODEL COMPARISON FOR SMA WITH THE MSRT MODEL HAVING ID = 1

COG	SAMPLE AVG. DEMAND	UICP SMA1	MSRT SMA1	UICP SMA2	MSRT SMA2
1H0D	4567.95	99.98	99.98	92.75	87.32
1H0A	511.46	99.86	99.87	97.67	96.92
1H2D	236.03	99.73	99.79	94.60	95.51
1H2A	140.91	99.54	99.61	94.40	94.86
1HS1	86.16	99.47	99.69	96.40	97.39
1H2B	24.17	98.62	99.31	88.90	92.62
1H3E	8.57	97.54	98.61	91.95	94.33
1H4F	0.84	93.30	99.00	86.56	98.31
1H1F	0.40	84.35	99.02	84.36	98.75

Table 5. MODEL COMPARISONS FOR SMA WITH THE MSRT MODEL HAVING ID = RP

COG	SAMPLE AVG. DEMAND	UICP SMA1	MSRT SMA1	UICP SMA2	MSRT SMA2
1H0D	4567.95	99.98	99.98	92.75	89.09
1H0A	511.46	99.86	99.86	97.67	96.73
1H2D	236.03	99.73	99.78	94.60	95.43
1H2A	140.91	99.54	99.60	94.40	94.55
1HS1	86.16	99.47	99.64	96.40	96.97
1H2B	24.17	98.62	99.16	88.90	91.11
1H3E	8.57	97.54	98.32	91.95	93.26
1H4F	0.84	93.30	98.46	86.56	97.42
1H1F	0.40	84.35	98.64	84.36	98.66

1. SMA Analysis and Observations

Relative to the UICP model, the MSRT model provides improved or equivalent SMA performance in all cases except for SMA2 in the case of very high demand items. For both measures of SMA the improvement in performance provided by the MSRT

model becomes greater as the average demand of the group of items processed becomes smaller. It is interesting to note that, in general, the performance of both the UICP and MSRT models deteriorates as the average demand of the population decreases. The better performance of the MSRT model then results from the fact that its SMA values decrease at a slower rate than those of the UICP model. ✓

Comparison of the performance of the three MSRT models, (depth initialized at 0, 1 or the reorder point) shows remarkably similar performance with very few differences in SMA greater than $\pm 1\%$. Again, the MSRT model with depth initialized at zero provides the best results. ✓

C. AVERAGE DAYS DELAY (ADD)

Average Days Delay measures how long on the average the supply system takes to fill a requisition, on the average aggregated over all requisitions. ADD for each four-digit cog is computed two different ways as follows:

$$ADD1 = \frac{\left[365 \times \sum_{i=1}^n [TWEB_i] \right]}{\left[4 \times \sum_{i=1}^n [W] \right]};$$

$$ADD2 = \frac{\left[365 \times \sum_{i=1}^n [TWEB_i] \times \left[\frac{D_i}{W_i} \right] \right]}{\left[4 \times \sum_{i=1}^n D_i \right]};$$

where:

TWEB = Time-weighted average number of requisitions backordered per year for item i.

ADD1 is strictly a requisition-based calculation. ADD2 begins as requisition-based but is converted to demand-based by factoring in average requisition size. Tables 6 and 7 give the ADD results.

Table 6. AVERAGE DAYS DELAY (ADD1)

COG	SAMPLE AVERAGE DEMAND	UICP ADD1	MSRT ADD1 ID = 0	MSRT ADD1 ID = 1	MSRT ADD1 ID = R
1H0D	4567.95	3.80	27.69	27.79	16.11
1H0A	511.46	1.86	4.80	4.80	3.72
1H2D	236.03	7.92	9.50	9.50	8.63
1H2A	140.91	7.82	8.70	8.70	8.94
1HS1	86.16	3.77	3.95	3.98	4.16
1H2B	24.17	26.94	18.99	19.44	23.62
1H3E	8.57	21.39	17.81	18.00	20.27
1H4F	0.84	65.15	4.79	6.85	11.49
1H1F	0.40	122.74	7.95	10.58	11.35

Table 7. AVERAGE DAYS DELAY (ADD2)

COG	SAMPLE AVERAGE DEMAND	UICP ADD2	MSRT ADD2 ID = 0	MSRT ADD2 ID = 1	MSRT ADD2 ID = R
1H0D	4567.95	2.03	0.58	0.59	0.89
1H0A	511.46	2.27	0.64	0.64	0.71
1H2D	236.03	1.94	1.03	1.03	1.05
1H2A	140.91	2.52	1.45	1.45	1.49
1HS1	86.16	2.21	1.28	1.28	1.37
1H2B	24.17	13.10	9.22	9.30	10.25
1H3E	8.57	16.07	5.30	5.35	6.19
1H4F	0.84	50.44	6.31	8.55	11.26
1H1F	0.40	82.66	26.46	33.18	35.22

1. ADD Analysis and Observations

The results of the ADD1 MOE are slightly inconsistent. In the case of ADD1 the MSRT model performs worse than the UICP model for high demand items and better than the UICP model for low demand items. Without exception, however, the MSRT models perform better than the UICP model for ADD2. Once again, the improvement in performance increases as the average demand of the group decreases. The

performances of the three forms of the MSRT models are similar with the depth initialized at zero being the best.

D. AVERAGE DAYS DELAY FOR BACKORDERED REQUISITIONS (ADDBO)

Average Days Delay for Backordered Requisitions measures how long an average backordered requisition remains on backorder before it is filled. ADDBO is a standard CARES requisition-based MOE. The formula is:

$$ADDBO = \frac{ADD1}{SMA2};$$

Table 8 gives the ADDBO results.

Table 8. AVERAGE DAYS DELAY FOR BACKORDERED REQUISITIONS (ADDBO)

COG	SAMPLE AVERAGE DEMAND	UICP ADDBO	MSRT ADDBO ID = 0	MSRT ADDBO ID = 1	MSRT ADDBO ID = \hat{R}
1H0D	4567.95	52.35	219.43	219.11	147.63
1H0A	511.46	80.04	155.82	155.82	113.86
1H2D	236.03	146.64	211.63	211.63	188.77
1H2A	140.91	139.60	169.08	169.08	163.99
1HS1	86.16	104.61	152.12	152.28	137.50
1H2B	24.17	242.62	262.20	263.23	265.82
1H3E	8.57	265.76	316.39	316.95	300.76
1H4F	0.84	484.59	379.26	405.95	446.11
1H1F	0.40	784.95	822.79	845.48	845.73

1. ADDBO Analysis and Observations

An quick analysis of the results for this MOE demonstrates a clear advantage to the UICP model.

E. DAYS OF SAFETY LEVEL

Days of safety level measures the amount of average stock on hand to protect against a stockout during leadtime. The higher the days of safety level the lower the risk of a stockout. The formula for days of safety level, which is computed by four-digit cog, is:

$$DOSL = \frac{365 \times \sum_{i=1}^n [C_i \times SL_i]}{\sum_{i=1}^n [4 \times C_i \times D_i]};$$

where:

DOSL = Cost weighted average safety level in days of supply at the forecasted mean quarterly demand rate of usage;

SL = Safety Level (Item maximum depth – reorder quantity – leadtime demand in units for item i); and

C = Unit price for item i.

The UICP reorder quantity was also used for the reorder quantity of the MSRT model. Table 9 gives the days of safety level results.

Table 9. DAYS OF SAFETY LEVEL (DOSL)

COG	SAMPLE AVERAGE DEMAND	UICP DOSL	MSRT DOSL ID = 0	MSRT DOSL ID = 1	MSRT DOSL ID = \hat{R}
1H0D	4567.95	48.03	69.38	68.65	51.81
1H0A	511.46	138.07	146.81	146.81	138.37
1H2D	236.03	222.76	232.77	232.77	222.72
1H2A	140.91	222.25	224.41	224.41	222.24
1HS1	86.16	223.56	247.14	246.37	224.34
1H2B	24.17	164.56	243.19	238.35	190.46
1H3E	8.57	287.67	360.96	359.49	302.76
1H4F	0.84	360.06	779.76	649.53	489.00
1H1F	0.40	413.09	1181.84	627.79	557.59

1. Days of Safety Level Analysis and Observations

An analysis of the days of safety level MOE shows that the MSRT model with item depths initialized at either 0, 1 or the reorder point clearly outperforms the UICP model. As before, the degree of improvement increases as the average demand of the group decreases.

F. CPU RUN TIME

Central Processor Unit (CPU) run time measures how long the computer takes to compute the optimal depth for each model. CPU run time is an important MOE because any additional run time may affect the ICP's if their ADP capacity is already nearing its limits. Table 10 gives the CPU run time results.

Table 10. CPU RUN TIME (CPURT) IN MINUTES

COG	SAMPLE AVERAGE DEMAND	SAMPLE SIZE	UICP CPURT	MSRT CPURT ID = 0	MSRT CPURT ID = 1	MSRT CPURT \hat{R} ID = \hat{R}
1H0D	4567.95	11	0.01	14.18	13.84	5.92
1H0A	511.46	100	0.10	38.60	37.96	16.69
1H2D	236.03	79	0.01	14.22	14.07	6.58
1H2A	140.91	100	0.02	15.82	15.63	5.99
1HS1	86.16	282	0.05	49.13	47.85	29.00
1H2B	24.17	492	0.08	48.71	45.51	26.73
1H3E	8.57	583	0.09	29.80	28.48	13.30
1H4F	0.84	882	0.15	9.05	8.06	5.06
1H1F	0.40	1420	0.20	8.49	8.05	5.25

1. CPURT Analysis and Observations

As expected, the MSRT model with its marginal analysis procedure for determining optimal item depths under a budget constraint requires significantly longer CPU run time than the UICP model. Initializing the depth of each item at the UICP computed reorder point decreased the MSRT model run time by about 50%. ✓

The run times encountered for the MSRT model during this research were significant. However, these can be reduced by use of VS FORTRAN, more efficient programming techniques and the more up-to-date hardware available at the ICPs. The run times are probably comparable to those encountered when a new λ value is being computed selected by CARES for the UICP model. The value of λ is not changed very often. ✓ The long runs to recompute maximum depths for the MSRT model need not occur very often either. Once the depths have been computed, each item's MSRT value could be used and is available as a subsequent goal for fine tuning its depth on a quarterly basis, if that is desired.

G. DEPTH CHURN

To assess the changes in maximum depth that would be expected from implementing the model, the "depth churn" between the UICP model and the MSRT model with $ID = 1$ was computed. For item i , this churn is defined as:

$$\begin{aligned} \text{Churn}_i &= \text{UICP Model Maximum Depth}_i - \text{MSRT Model Depth}_i \\ &= (Q_i + R_i) - SW_i \end{aligned}$$

The churn data in Appendix I represents the four-digit cogs with the most extreme and least extreme churn. Each churn value is presented with its frequency of occurrence. Cogs 1H0A and 1H0D showed the most extreme churn while cogs 1H3E and 1H4F showed the least.

1. Depth Churn Analysis and Observations

The characteristics of the items that showed the greatest degree of churn, one + and one -, for each of the four-digit cogs listed in Appendix I are presented in Tables 11 and 12 below. The \hat{Q} value, which is the same for both models, is included along with each item's unit price and quarterly demand. Depth is in units of inventory.

Table 11. COGS WITH LEAST CHURN

COG	UICP DEPTH	MSRT DEPTH	CHURN	\hat{Q}	UNIT PRICE	QTRLY DMD
1H3E	8151	10045	-1894	805	38.00	508.64
1H3E	87	67	20	20	5920.00	6.19
1H4F	984	1499	-515	676	6.30	56.24
1H4F	40	25	15	20	7420.00	1.61

✓ Keeping in mind that a negative churn indicates a greater depth for the MSRT model, it is clearly seen that the MSRT model places greater emphasis on low-cost, high-demand items. This is the expected result given that the MSRT model criteria for increasing an item's depth is based on a comparison of the cost-weighted ratios of improvement in time-weighted units short.

Table 12. COGS WITH GREATEST CHURN

COG	UICP DEPTH	MSRT DEPTH	CHURN	\hat{Q}	UNIT PRICE	QTRLY DMD
1H0A	65653	76059	-10406	10411	4.70	10078.11
1H0A	2018	1886	132	776	25.50	349.17
1H0D	50199	57416	-7217	11219	1.50	7666.90
1H0D	1294	1148	146	589	43.50	288.37

VI. SUMMARY AND RECOMMENDATIONS

A. SUMMARY

This thesis is part of the Naval Postgraduate School's continuing effort to introduce more effective inventory models into the Naval Supply System's management of wholesale level inventories. The specific objective of this thesis was to develop an inventory model for consumable items having the objective function of minimizing the aggregate mean supply response time (MSRT) and then to compare the results of this model with the current consumable UICP model. The MSRT consumable model has the same readiness related objective as the recently implemented wholesale provisioning model for consumables.

This objective was accomplished by developing the mathematics for the new model, developing computer programs for both models, processing ICP inventory management data through both models and conducting a comparative evaluation of the results using various measures of effectiveness. The main FORTRAN computer program is presented in Appendix A. The major subroutines are presented in Appendices B through H.

B. CONCLUSIONS

This research demonstrated conclusively that the MSRT model improves supply system performance for consumable items with no increase in investment. 9

1. Standard Measures of Effectiveness Summary

In addition to being superior relative to the aggregate MSRT measure of effectiveness, the MSRT model provides significant improvements over the UICP model in the following supply system performance measures for items with a low, average quarterly demand:

1. Supply material availability (SMA);
2. Average days delay (ADD); and
3. Days of safety level.

The improvement provided by the MSRT model decreased as the average quarterly demand of the groups of items processed increased. Performance of the two models was equivalent for the items with a high average quarterly demand. This trend was consistently observed across all measures of effectiveness with the exception of Average Days Delay for Backorders.

2. CPU Run Time Summary

The CPU run time required by the MSRT model with its marginal analysis optimization procedure was significantly larger than the run times required by the UICP model. The amount of run time required for any group of items was found to be sensitive to the average quarterly demand of the four-digit cog's population and the number of items in the cog. Since the focus of this research was an initial comparison of the performance of the two inventory models, programming efficiencies were not pursued.

Reductions in CPU run time could be obtained by:

1. Using VS FORTRAN instead of WATFOR 77.
2. Using more modern computer hardware.
3. Using more efficient programming techniques.

C. RECOMMENDATIONS

Replacement of the UICP consumable model with the MSRT model should be considered by the ICPs. While the long computer run times are a disadvantage of the MSRT model, it should not be necessary to make such runs every quarter. Instead, each item's depth can be adjusted to retain its same MSRT value as when the full four-digit cog optimization was last run. This approach is similar to that used to determine the λ shortage cost. ✓

Viewing consumables as a limiting case of repairables, research should continue towards developing an MSRT model applicable to the wholesale inventory management of repairable items.

APPENDIX A. MAIN PROGRAM

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PROGRAM REPMOD
C TEST WHOLESALE CONSUMABLE REPLENISHMENT MODELS
C THIS PROGRAM RUNS BOTH THE UICP MODEL AND THE MSRT MODEL.
C THE UICP MODEL INITIALIZES X AT ZERO, ONE OR THE UICP COMPUTED
C REORDER POINT DEPENDING ON WHICH STEPS ARE COMMENTED OUT IN THE
C SUBPROGRAM "MODOPT" (STEPS 658 TO 670). THE PROGRAM ALSO COMPUTES
C THE CHURN BETWEEN THE TWO MODELS AND STORES IT IN A FILE THAT IS
C OPENED IN STEP 65.
CHARACTER*23 NAME2/'MIN INVESTMENT LEVEL'/
CHARACTER*23 NAME3/'MINIMUM MSRT '/
CHARACTER*23 NAME1/'UICP CONSUMABLES MODEL '/
CHARACTER*4 Q1/'1 '/,Q2/'4D '/,Q3/'EQQ '/,Q4/'D '/,
CHARACTER*4 RQ1/'1 '/,RQ2/'4D '/,RQ3/'EQQ '/,RQ4/'D '/
CHARACTER*4 RQ5/'UICP '/,Q5/'UICP '/
CHARACTER*4 QM, QMR
CHARACTER*1 PRIND(1500)
REAL BB(10),QBASIC,QTEMP
INTEGER STOP(1500),MARK(1500),LOT(1500),MD,PBP(1500),RLC(1500)
INTEGER N,NN,X(1500),NSO(1500),QMIN(1500),NRPR(1500),XMSRT(1500)
INTEGER Y(1500),QS,Q21,Q2C,Q22,NPO,NOPT,KK,NI,ROP(1500)
INTEGER RESV(1500),BO(1500),PPRLT(1500),PPR1(1500),PPR2(1500)
INTEGER PPR3(1500),PPR4(1500),AD(1500),CD(1500),OHRFI(1500)
INTEGER XCHURN(1500)
INTEGER OHNRFI(1500),PPR1YR(1500),UPLIM,ROP1,XUICP(1500)
REAL D(1500),PCLT(1500),LAM(1500),SL(1500)
REAL H,RISK,Z(1500),ZN(1500),T(1500),Q(1500),QQ(1500)
REAL C1(1500),HC(1500),POC(1500),CHRCNST(1500),CHRNTO
CHARACTER*4 COG1(1500),COG2(1500)
REAL MODMST,MODNSF,MSRTG(10),MSRTGG,BGT(10),PVAR(1500),RST(1500)
REAL DMAD(1500),RF(1500),C11(1500),E(1500),RMIN(1500),RMAX(1500)
REAL TOV(2),QRI(1500),QRR(1500),QR(1500)
REAL QQR(1500),AS1(1500),SLC(1500),OBSS(1500)
CHARACTER*4 COGG1(1500),COGG2(1500)
REAL*8 B,BUDGG
REAL RESLT,B19PT1,B19PT2,B19PT3,B19PT4,B19MIN,B19MAX
COMMON SN(1500,9)
EXTERNAL MODMST
C **** THE NEXT PARAMETER MUST BE SPECIFIED WHENEVER A NEW COG IS
C **** INTRODUCED.
C **** THIS NUMBER IS PROVIDED BY THE PRINTOUT FROM TEMPDATA PROGRAM.
N=1500
C **** THE NEXT NUMBER SPECIFIES FULL TABLE LISTING(NPO=0) OR ONLY
C **** A SUMMARY (NPO=1)
NPO=1
NNN=0
NN1=0
C **** THE VALUE OF Q MUST BE COMPUTED. THE PARAMETER MQ TELLS THE
C **** SUBROUTINE ORDQAN WHICH VALUE IS DESIRED; MQ=1 FOR Q=1, MQ=2 FOR
C **** Q=4*D, MQ=3 FOR Q=EQQ, MQ=4 FOR Q=D, MQ=5 FOR QICP.
C **** QM IS EITHER Q1, Q2, Q3, Q4 OR Q5, RESPECTIVELY.
MQ=5

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QM=Q5
QMR=RQ5
C *** NN IS THE NUMBER OF MEASURES OF
C *** PERFORMANCE; IF SMA AND MSRT ARE USED THEN NN=2.
NOPT=2
NN=2
C *** A COUNT OF VIABLE ITEMS MUST MADE (NOT HAVING STRANGE DATA).
KK=0
NI=0
OPEN (UNIT=10, FILE='COA', STATUS='OLD')
OPEN(UNIT=11, FILE='CHRNA', STATUS='NEW')
DO 23 I=1, N
22 READ(10, 898, END=24) COG1(I), COG2(I), MARK(I), (SN(I, J), J=1, 9), SLC(I)
*PRIND(I), OBSO(I), E(I), PCLT(I), NRPR(I), C1(I), C11(I), D(I),
*PVAR(I), RF(I), RESV(I), BO(I), PPRLT(I), PPR1(I), PPR2(I), PPR3(I),
*PPR4(I), OHRFI(I), OHNRFI(I), AD(I), CD(I),
*AS1(I), DMAD(I), LOT(I), NSO(I), QMIN(I)
898 FORMAT (2A2, I1, 9A1, 1X, A1, 1X, A1, 6X, F3. 2, F3. 3, F4. 2, 7X, I4, 3F10. 2, 10X,
* 2F10. 2, 2I8, 5I5, I7, 1X, I7, 1X, 2I8, F8. 0, 38X, F10. 2, 2I8, I5)
IF(D(I).GT. 250000.)GO TO 22
IF(D(I).LT. 0. 0)GO TO 22
IF(C1(I).GT. 999999.)GO TO 22
IF (C1(I).LT. . 01)GO TO 22
IF(LOT(I).NE. 0)GO TO 22
IF(COG1(I).NE. '1H')GO TO 22
KK=KK+1
NI=NI+1
23 CONTINUE
24 DO 5 I=1, NI
COGG1(I)=COG1(I)
COGG2(I)=COG2(I)
RMIN(I)=. 10
IF(COG2(I).EQ. '4A'.OR. COG2(I).EQ. '3A'.OR. COG2(I).EQ. '2A'.OR.
*COG2(I).EQ. '1A'.OR. COG2(I).EQ. '0A')THEN
RMAX(I)=. 30
LAM(I)=1500
PBP(I)=0
RLC(I)=1
ELSEIF(COG2(I).EQ. '4B'.OR. COG2(I).EQ. '3B'.OR. COG2(I).EQ. '2B'.OR.
*COG2(I).EQ. '1B'.OR. COG2(I).EQ. '0B')THEN
RMAX(I)=. 40
LAM(I)=1000
PBP(I)=0
RLC(I)=1
ELSEIF(COG2(I).EQ. '4D'.OR. COG2(I).EQ. '3D'.OR. COG2(I).EQ. '2D'.OR.
*COG2(I).EQ. '1D'.OR. COG2(I).EQ. '0D')THEN
RMAX(I)=. 30
LAM(I)=2000
PBP(I)=0
RLC(I)=1
ELSEIF(COG2(I).EQ. '4E'.OR. COG2(I).EQ. '3E'.OR. COG2(I).EQ. '2E'.OR.
*COG2(I).EQ. '1E'.OR. COG2(I).EQ. '0E')THEN
RMAX(I)=. 40
LAM(I)=2000
PBP(I)=0
RLC(I)=1

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ELSEIF(COG2(I).EQ.'4C'.OR.COG2(I).EQ.'3C'.OR.COG2(I).EQ.'2C')THEN
  RMAX(I)=.50
  LAM(I)=500
  PBP(I)=0
  RLC(I)=1
ELSEIF(COG2(I).EQ.'1C'.OR.COG2(I).EQ.'0C')THEN
  RMAX(I)=.99
  LAM(I)=500
  PBP(I)=20
  RLC(I)=0
ELSEIF(COG2(I).EQ.'4F'.OR.COG2(I).EQ.'3F'.OR.COG2(I).EQ.'2F')THEN
  RMAX(I)=.50
  LAM(I)=750
  PBP(I)=0
  RLC(I)=1
ELSEIF(COG2(I).EQ.'1F'.OR.COG2(I).EQ.'0F')THEN
  RMAX(I)=.99
  LAM(I)=500
  PBP(I)=20
  RLC(I)=0
ELSEIF(COG2(I).EQ.'N1'.OR.COG2(I).EQ.'N2'.OR.COG2(I).EQ.'N3')THEN
  RMAX(I)=.35
  LAM(I)=1500
  PBP(I)=0
  RLC(I)=1
ELSE
  RMAX(I)=.35
  LAM(I)=2500
  PBP(I)=0
  RLC(I)=1
ENDIF
STOP(I)=0
IF(RF(I).EQ.0.0)RF(I)=D(I)
IF(RF(I).GT.D(I))RF(I)=D(I)
IF(PCLT(I).GT.18.)PCLT(I)=18.
IF(PCLT(I).EQ.0.0)PCLT(I)=5.0
IF(C11(I).GT.999999.)C11(I)=999999.
IF(C11(I).LT..01)C11(I)=C1(I)
IF(AS1(I).LT.0.0)AS1(I)=0.0
IF(AS1(I).GT.250000.)AS1(I)=250000.
IF(OBSO(I).LE..01)OBSO(I)=.01
IF(OBSO(I).GT.1.0)OBSO(I)=1.0
IF(E(I).LT..001)E(I)=.001
UPLIM=AMAXO(100000,(NINT(16*D(I))))
PPR1YR(I)=PPR1(I)+PPR2(I)+PPR3(I)+PPR4(I)
IF(OHRFI(I).LT.0)OHRFI(I)=0
IF(OHRFI(I).GT.UPLIM)OHRFI(I)=UPLIM
IF(OHNRFI(I).LT.0)OHNRFI(I)=0
IF(OHNRFI(I).GT.UPLIM)OHNRFI(I)=UPLIM
IF(AD(I).LT.0)AD(I)=0
IF(AD(I).GT.UPLIM)AD(I)=UPLIM
IF(CD(I).LT.0)CD(I)=0
IF(CD(I).GT.UPLIM)CD(I)=UPLIM
IF(BO(I).LT.0)BO(I)=0
IF(BO(I).GT.UPLIM)BO(I)=UPLIM
IF(RESV(I).LT.0)RESV(I)=0

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IF (RESV(I).GT.UPLIM)RESV(I)=UPLIM
IF (PPRLT(I).LT.0)PPRLT(I)=0
IF (PPRLT(I).GT.UPLIM)PPRLT(I)=UPLIM
IF (PPR1YR(I).LT.0)PPR1YR(I)=0
IF (PPR1YR(I).GT.UPLIM)PPR1YR(I)=UPLIM
Z(I)=D(I)*PCLT(I)
IF (Z(I).LE.0.0)THEN
    Z(I)=0.0
    PVAR(I)=0.0
    GO TO 5
ENDIF
4 VTMR=150.
VTMRP=PVAR(I)/Z(I)
IF (VTMRP.GE.VTMR)PVAR(I)=0.0
IF (PVAR(I).NE.0.0)GO TO 5
PVAR(I)=4.85*Z(I)**1.5
5 CONTINUE
MSRTGG=0.0
CALL ICPMOD(NI,H,B,X,Z,C1,C11,D,QQ,NRPR,RF,PVAR,LOT,
*DMAD,E,LAM,MARK,PBP,SLC,RMIN,RMAX,RLC,NSO,AS1,
*QQR,QMIN,OBSO,PRIND,HC,POC)
VSL=0.0
VAT=0.0
DO 10 I=1,NI
* PRINT*, QQ(I),QQR(I)
SL(I)=X(I)-QQR(I)-Z(I)
XUICP(I)=X(I)
VSL=VSL+C11(I)*SL(I)
VAT=VAT+C11(I)*D(I)*4.
10 CONTINUE
SLD=VSL*365./VAT
CALL PRTOUT(1,NAME1,QM,B,QQ,QRI,QQR,N,NI,NN,X,Z,C11,D,MSRTGG,
*COGG1,COGG2,NPO,TOV,QMR,PBP,PVAR,SLD,PCLT,NNN,NN1)
MOD=1
CALL ICPSMA(NI,COGG1,D,RF,DMAD,X,QQ,QMIN,Z,PBP,PVAR,H,RMAX,LAM,
*RMIN,MARK,SLC,PCLT,C1,E,MOD,QRI,NSO,
*NRPR)
MSRTGG=TOV(2)
BUDGG=B
DO 41 I=1,NI
    IF(MQ.EQ.5)Q(I)=QQ(I)
    IF(MQ.EQ.5)GO TO 41
41 CONTINUE
MOD=3
CALL MODOPT(NI,NNN,B,MODMST,X,Z,D,QQR,C11,STOP,MSRTGG,MOD,PBP,
*PVAR,Q,NN1)
***** COMPUTE ROP(I)
DO 7777 I= 1, NI
    ROP(I)=X(I)-Q(I)
    XMSRT(I)=X(I)
7777 CONTINUE
VSL=0.0
VAT=0.0
DO 43 I=1,NI
SL(I)=X(I)-Q(I)-Z(I)
IF (SL(I).LT.0.0)SL(I)=0.0

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VSL=VSL+C11(I)*SL(I)
43 VAT=VAT+C11(I)*D(I)*4.
SLD=VSL*365./VAT
CALL PRTOUT(3,NAME3,QM,B,Q,QRI,QQR,N,NI,NN,X,Z,C11,D,MSRTGG,
*COGG1,COGG2,NPO,TOV,QMR,PBP,PVAR,SLD,PCLT,NNN,NN1)
CALL ICPSMA(NI,COGG1,D,RF,DMAD,X,QQ,QMIN,Z,PBP,PVAR,H,RMAX,LAM,
*RMIN,MARK,SLC,PCLT,C1,E,MOD,QRI,NSO,
*NRPR)
CHRNROT=0.0
PRINT*
WRITE (6,8184)
8184 FORMAT('0','ITEM    CHURN          DMD    UNIT PRICE    CHURN PRICE')
DO 8181 I=1, NI
    XCHURN(I) = XUICP(I)-XMSRT(I)
    CHRNCS(I)=XCHURN(I)*C11(I)
    CHRNROT=CHRNROT+CHRNCS(I)
    WRITE(11,8186)XCHURN(I)
8186    FORMAT (1X,I8)
    WRITE(6,8183)I,XCHURN(I),D(I),C11(I),CHRNCS(I)
8183    FORMAT('0',I4,I8,F10.2,F13.2,F16.2)
8181 CONTINUE
WRITE (6,8185)CHRNROT
8185 FORMAT('0','SUM OF CHURN PRICES IS $ ',F18.2)
*1500 CONTINUE
99 STOP
END

```

*THE INPUT FOR THE READ STATEMENT OF THE MAIN PROGRAM IS IN THE CARES
 *(COMPUTATION AND RESEARCH EVALUATION SYSTEM) III FORMAT.

*VARIABLE NAME	DATA	DEN(S)	CARES CC#
*COG1	COG	C003	1 - 2
*COG2	COG	C003W	3 - 4
*MARK	MARK CODE		5
*SN	STOCK NUMBER	D046D	6 - 14
*SLC	SHELF LIFE CODE	C028	16
*PRIND	PROCUREMENT INDICATOR	D025E	18
*OBSO	OBSOLESCENCE RATE	B057	25 - 27
*E	ESSENTIALITY CODE	C008C	28 - 30
*PCLT	PROCUREMENT LEADTIME	B011A	31 - 34
*NRPR	NUMBER OF POLICY RECEIVERS		42 - 45
*C1	REPLACEMENT PRICE	B055	46 - 55
*C11	UNIT PRICE	B053	56 - 65
*D	QUARTERLY DEMAND	B074	66 - 75
*PVAR	PROCUREMENT VARIANCE	B019A	86 - 95
*RF	REQUISITION FREQUENCY	A023B	96 - 105
*RESV	RESERVATIONS	A013A	106 - 113
*BO	BACKORDERS	A011	114 - 121
*PPRLT	PPRS DURING LEADTIME		122 - 126
*PPR1	PPRS 1ST QTR AFTER LT		127 - 131
*PPR2	" 2ND " " "		132 - 136
*PPR3	" 3RD " " "		137 - 141
*PPR4	" 4TH " " "		142 - 146
*OHRFI	ON-HAND SYSTEM RFI		147 - 154
*OHNRFI	ON-HAND SYSTEM NRFI		155 - 162
*AD	AWARDED DUES		163 - 170

*CD	COMMITTED DUES		171 - 178
*AS1	SET-UP COST	B058	179 - 186
*DMAD	DEMAND MAD	A019(2)+A019A(2)	225 - 234
*LOT	LIFE OF TYPE QTY	B070	235 - 242
*NSO	REORDER LVL LOW LIMIT QTY	B020	243 - 250
*QMIN	MINIMUM PRODUCTION QTY	B061B	251 - 255

APPENDIX B. SUBROUTINE ICPMOD

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C *** THE CURRENT ICP CONSUMABLES MODEL
C *** THIS SUBROUTINE COMPUTES ONLY THE PROCUREMENT Q AND ROP.
SUBROUTINE ICPMOD(N,H,B,X,Z,C1,C11,D,Q,NRPR,RF,PVAR,LOT,
*DMAD,E,LAM,MARK,PBP,SLC,RMIN,RMAX,RLC,NSO,AS1,QQR,QMIN,
*OBSO,PRIND,HC,POC)
  INTEGER N,NRPR(N),LOT(N),MARK(N),Y(1500),R121,Q8,Q9,QMIN(N)
  INTEGER X(N),NSO(N),RLC(N),PBP(N),ROP(1500),ROP1,I,J,K
  CHARACTER*1 PRIND(N)
  REAL Z(N),C1(N),D(N),RF(N),PVAR(N),DMAD(N),AS1(N)
  REAL SL(1500),RMIN(N),RMAX(N),C3(1500),RISK(1500),E(N),SLC(N),H
  REAL Q1,Q(N),LAM(N),C11(N)
  REAL QQR(N),AA,AC,RRCT,HC(N),OBSO(N),POC(N)
  REAL TEMP1,TEMP2,T1,Q1A,Q1B,Q1C,Q1D,Q1E,Q1SQRT,Q1MAX
  REAL OLP1P2,TP1P2,Z1B23H,B19AOC,TSTRSK,RISKT(50),TVALU,RISKJ
  REAL RESLT,VTMTR,PVTMR,QRATIO,VRATIO,VLOG,PROB,SMPROB,B19PT3
  REAL B19PT1,B19PT2,B19PT4,B19MIN,B19MAX,B21MIN,B21PT1,B21PT2
  REAL*8 B
  B=0.0
  ***** RISKTABLE FOR THE NORMAL DISTRIBUTION
  RISKT(1) = 0.46017120
  RISKT(2) = 0.42074060
  RISKT(3) = 0.38206860
  RISKT(4) = 0.33457830
  RISKT(5) = 0.30853750
  RISKT(6) = 0.27485310
  RISKT(7) = 0.24196370
  RISKT(8) = 0.21185540
  RISKT(9) = 0.18406010
  RISKT(10) = 0.15865530
  RISKT(11) = 0.13566610
  RISKT(12) = 0.11506970
  RISKT(13) = 0.09680050
  RISKT(14) = 0.08075670
  RISKT(15) = 0.06680720
  RISKT(16) = 0.05479930
  RISKT(17) = 0.04456550
  RISKT(18) = 0.03593030
  RISKT(19) = 0.02871660
  RISKT(20) = 0.02275010
  RISKT(21) = 0.01786440
  RISKT(22) = 0.01390340
  RISKT(23) = 0.01072410
  RISKT(24) = 0.00819750
  RISKT(25) = 0.00620970
  RISKT(26) = 0.00466120
  RISKT(27) = 0.00346700
  RISKT(28) = 0.00255510
  RISKT(29) = 0.00186580
  RISKT(30) = 0.00134990
  RISKT(31) = 0.00096760
  RISKT(32) = 0.00068710

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RISKT(33) = 0.00048340
RISKT(34) = 0.00033690
RISKT(35) = 0.00023260
RISKT(36) = 0.00015910
RISKT(37) = 0.00010780
RISKT(38) = 0.00007230
RISKT(39) = 0.00004810
RISKT(40) = 0.00003170
RISKT(41) = 0.00002070
RISKT(42) = 0.00001330
RISKT(43) = 0.00000850
RISKT(44) = 0.00000540
RISKT(45) = 0.00000340
RISKT(46) = 0.00000211
RISKT(47) = 0.00000130
RISKT(48) = 0.00000079
RISKT(49) = 0.00000048
RISKT(50) = 0.00000029
DO 6 I=1,N
***** COMPUTE HOLDING COST (HC). HC = STORAGE RATE(.01) + TIME
***** PREFERENCE RATE(.10) + OBSOLETE RATE (OBSO(I))
      HC(I)=OBSO(I)+.11
***** COMPUTE AND CONSTRAIN THE RISK
      TEMP1=HC(I)*D(I)
      TEMP2=RF(I)*LAM(I)*E(I)
      IF(TEMP2.EQ.0.0)THEN
        T1=0.0
      ELSE
        T1=AMIN1(TEMP1*C1(I)/TEMP2,999999.0)
      ENDIF
      RISK(I)=T1/(T1+1.0)
      RISK(I)=AMAX1(RISK(I),RMIN(I))
      RISK(I)=AMIN1(RISK(I),RMAX(I))
***** COMPUTE PROCUREMENT ORDER COST (POC)
      IF(MARK(I).EQ.0.OR.MARK(I).EQ.1.OR.MARK(I).EQ.2)THEN
        POC(I)=660.
      ELSEIF(MARK(I).EQ.3.OR.MARK(I).EQ.4.AND.(8000**2*HC(I)*
*(AMAX1((1-RISK(I)), (1-.5)))/8*(660.+AS1(I)).GT.(C1(I)*D(I))))THEN
        POC(I)=660.
      ELSEIF(PRIND(I).EQ.'0'.OR.PRIND(I).EQ.'B'.OR.PRIND(I).EQ.'2')
*      THEN
        POC(I)=1940.
      ELSE
        POC(I)=1970.
      ENDIF
***** COMPUTE AND CONSTRAIN REORDER POINT (ROP)
***** BASIC REORDER LEVEL *****
*** THE TEMPORARY VARIABLE NAMES USED IN THE REMAINDER OF THIS
*** SUBPROGRAM WERE USED IN ORDER TO MATCH AS CLOSELY AS POSSIBLE
*** THE VARIABLE NAMES USED IN THE ACTUAL UICP PROGRAM
      OLP1P2=1.0-RISK(I)
      TP1P2=RISK(I)
      Z1B23H=Z(I)
      B19AOC=PVAR(I)
      IF(MARK(I).EQ.0)GO TO 1500

```

```

      IF (Z1B23H.LT.PBP(I))GO TO 1000
***** NORMAL DISTRIBUTION *****
500   TSTRSK=TP1P2
      IF(TP1P2.LE.0.5)GO TO 600
      TSTRSK=1.0-TP1P2
600   DO 650 K = 1, 50
      IF(TSTRSK.LT.RISKTB(K))GO TO 650
      TVALU=1.0*K
      IF (TSTRSK.EQ.RISKTB(K))GO TO 700
      J=K-1
      RISKJ=0.5
      IF(J.NE.0)RISKJ=RISKTB(J)
      TVALU=K-((TSTRSK-RISKTB(K))/(RISKJ-RISKTB(K)))
      GO TO 700
650   CONTINUE
      TVALU=50.0
700   IF(TP1P2.GT.0.5)TVALU=-TVALU
      TVALU=0.1*TVALU
800   K=0
      RESLT=Z1B23H
      IF(B19AOC.LE.0.0)GO TO 2500
      IF(TP1P2.NE.0.5)RESLT=Z1B23H+(TVALU*SQRT(B19AOC))
      GO TO 2500
***** NEGATIVE BINOMIAL DISTRIBUTION *****
1000  VTMR=1.01
      IF(Z1B23H.NE.0.0)VTMR=AMAX1(VTMR,(B19AOC/Z1B23H))
      PVTMR=VTMR-1.0
      QRATIO=PVTMR/VTMR
      VRATIO=Z1B23H/PVTMR
      VLOG=VRATIO*ALOG(VTMR)
      IF(VLOG.GT.6.9)GO TO 500
1100  K=0
      PROB=EXP(-VLOG)
      SMPROB=PROB
      GO TO 1300
1200  K=K+1
      PROB=((VRATIO+(K-1))/K)*QRATIO*PROB
      SMPROB=SMPROB+PROB
1300  IF(PROB.LE.0.0001)GO TO 500
      IF(SMPROB.LT.OLP1P2)GO TO 1200
      RESLT=1.0*K
      GO TO 2500
***** POISSON DISTRIBUTION *****
1500  IF (Z1B23H.GT.6.9)GO TO 500
1510  K=0
      PROB=EXP(-Z1B23H)
      SMPROB=PROB
      GO TO 1540
1520  K=K+1
      PROB=(Z1B23H/K)*PROB
      SMPROB=SMPROB+PROB
1540  IF(PROB.LE.0.0001)GO TO 500
      IF(SMPROB.LT.OLP1P2)GO TO 1520
1550  RESLT=1.0*K
      GO TO 2500
2500  RESLT=RESLT

```

```

      IF (D(I).GT.0.0)GO TO 3860
      RESLT=AMAX1(Z(I),FLOAT(NSO(I)),0.0)
      CALL SHFLIF(SL(I),SLC(I))
      GO TO 3990
3860   CALL SHFLIF(SL(I),SLC(I))
      B19PT3=SL(I)*D(I)+Z(I)
      IF (NSO(I).GT.100000.0)NSO(I)=0.0
      B19PT1=Z(I)+33.*D(I)
      B19PT2=AMAX1(RESLT,FLOAT(NRPR(I)))
      IF((SL(I)/4.).LT.7.0)GO TO 3900
      B19PT3=99999999.0
      GO TO 3920
3900   B19PT3=B19PT3*D(I)
3920   B19MIN=AMIN1(B19PT1,B19PT2,B19PT3)
      B19PT4=1.0*Z(I)
      B19MAX=AMAX1(B19MIN,B19PT4,FLOAT(NSO(I)),0.0)
3940   RESLT=B19MAX+0.999
3990   ROP(I)=AINT(RESLT)
6 CONTINUE
*** COMPUTE Q NEXT
DO 12 I=1,N
  Q1A=12.0*D(I)
  Q1B=D(I)
  Q1C=8.0*(POC(I)+AS1(I))*D(I)
  Q1D=HC(I)*C1(I)*AMAX1((1-RISK(I)),.5)
  Q1E=0.0
  IF(Q1D.GT.0.0)THEN
    Q1E=Q1C/Q1D
  ENDIF
  IF(Q1E.LE.0.0)THEN
    Q1SQRT=0.0
  ELSE
    Q1SQRT=SQRT(Q1E)
  ENDIF
  Q1MAX=AMAX1(Q1B,Q1SQRT)
  Q1=AMIN1(Q1MAX,Q1A)
  Q1=Q1+0.999
  IF((SL(I)/4.).LT.7.0)GO TO 4020
  Q(I)=Q1+0.999
  GO TO 4100
4020   B21PT1=AMAX1(ROP(I)-Z(I),0.0)
      B21PT2=SL(I)*D(I)-B21PT1
      B21MIN=AMIN1(B21PT2,Q1)
      Q(I)=B21MIN+0.999
*4100   IF(Q(I).LT.1.0)Q(I)=1.0
4100   Q(I)=AINT(Q(I))
      QQR(I)=Q(I)
      X(I)=ROP(I)+IFIX(QQR(I)+0.999)
      B=B+C11(I)*FLOAT(X(I))
12 CONTINUE
  RETURN
END

```

*
 *VARIABLES NOT IDENTIFIED IN APPENDIX 1
 *

*VARIABLE NAME	DATA
----------------	------

*N	NUMBER OF ITEMS BEING PROCESSED	
*H	(NOT USED)	
*B	BUDGET (INVESTMENT LEVEL)	
*X	DEPTH	
*Q	ECONOMIC ORDER QUANTITY	
*LAM	LAMBDA	(GIVEN IN THE MAIN PROGRAM)
*PBP	PROBABILITY BREAK POINT	"
*RMIN	MINIMUM RISK	"
*RMAX	MAXIMUM RISK	"
*RLC	REORDER LEVEL CONSTRAINT	"
*QQR	ECONOMIC ORDER QUANTITY	
*HC	HOLDING COST	
*		

APPENDIX C. SUBROUTINES/FUNCTIONS - MODOPT, MODMST AND GOALM

* IN THIS APPENDIX THREE SUBPROGRAMS HAVE BEEN LISTED TOGETHER
*BECAUSE THEY FUNCTION AS ONE SUBPROGRAM AND COULD HAVE BEEN WRITTEN
*AS SUCH.

```

      SUBROUTINE MODOPT(N,NNN,B,AMODEL,X,ZN,D,QR,C11,STOP,GOALG,MOD,PBP,
      *PVAR,Q,NN1)
C --- PERFORM OPTIMAL ALLOCATION FOR GIVEN MODEL USING
C --- MARGINAL ANALYSIS METHOD AND LOWER BOUNDING.
C --- N=NO. ITEMS
C --- B=INVESTMENT LEVEL OF STOCK FUND
C --- AMODEL=ENTRY POINT FOR MODEL TO USE (STANDARDIZED ARGUMENTS)
C --- X=OPTIMAL ALLOCATIONS PER ITEM
C --- ZN= MEAN DEMAND DURING RESUPPLY TIME OR PPV
C --- C1=PROCUREMENT COST FOR EACH ITEM
C --- RR=WORK VECTOR TO STORE RATIOS
      INTEGER N,NNN,K,MK,STEP,X(N),STOP(N),PBP(N),INDEX(1500),XL(1500)
      REAL ZN(N),QR(N),D(N),MR,RR(1500),SR,TRY,PVAR(N),Q(N)
      REAL MODNSF,MODMST,C11(N),GOALG
      REAL*8 B,BR,BUDLIM
      I=1
      SR=0.
      KK=1
      NN1=0
C --- INITIALIZE
      BUDLIM=B
      B=0.
      DO 2 I=1,N
C --- INITIALIZE STOP BEFORE OPTIMIZING ON INVESTMENT LEVEL(STOP=1 MEANS
C --- THAT THE LEVEL HAS HIT THE ITEM MSRT BOUND).
      *****THESE FIVE STEPS PUT X AT ROP*****
      *      RP(I) = X(I)-IFIX(QR(I))
      *      IF (X(I).GT.1) THEN
      *          X(I) = RP(I)
      *      ENDIF
      *      B = B+(X(I)*C11(I))
      *****THESE FOUR STEPS PUT X AT 1 OR 0*****
      *      IF(X(I).NE.0)THEN
      *          X(I)=1
      *          B=B+C11(I)
      *      ENDIF
      *****this step puts x at zero
      *      x(I)=0
      *      STOP(I)=0
      *      INDEX(I)=0
C      RR(I)=AMODEL(ZN(I),D(I),QR(I),C11(I),X(I)+1,STOP(I),PBP(I),
      *      PVAR(I))
      2 CONTINUE

```

```

12 STEP=0
C --- DO UNTIL MSRT OR BUDGET GOAL IS REACHED
20 CONTINUE
STEP=STEP+1
MK=0
MR=15000000.
IF(MOD.EQ.3)MR=0.
DO 30 K=1,N
    IF(STOP(K).EQ.1)GO TO 30
*    IF(INDEX(I).EQ.1)GO TO 30
    IF(RR(K).GE.MR)GO TO 30
    MR=RR(K)
    MK=K
30 CONTINUE
IF(MK.EQ.0) GO TO 50
C --- ALLOCATE ONE MORE UNIT OF ITEM MK IF POSSIBLE.
B=B+C11(MK)
IF(B.GE.BUDLIM)THEN
    B=B-C11(MK)
    GO TO 50
ENDIF
X(MK)=X(MK)+1
C --- NEXT CHECK TO SEE IF GOAL HAS BEEN ATTAINED.
* CALL GOALM(X,N,ZN,D,QR,TRY,GOALG,PBP,PVAR)
* IF(TRY.EQ.0.0)GO TO 50
SR=MR
RR(MK)=AMODEL(ZN(MK),D(MK),QR(MK),C11(MK),X(MK)+1,STOP(MK),
*PBP(MK),PVAR(MK))
GO TO 20
50 RETURN
END

C
C --- ROUTINE TO MINIMIZE MEAN SUPPLY RESPONSE TIME -- MSRT
REAL FUNCTION MODMST(ZZ,D,QR,C,K,STOP,PBP,PVAR)
C COMPUTE MARGIN ANALYSIS RATIOS ASSUMING
C POISSON DEMAND.
REAL ZZ,QR,C,MSRT,MSRTD,D,PVAR
INTEGER K,STOP,PBP
IF(ZZ.NE.0.0)GO TO 10
MODMST=0.0
MSRT=-0.0001
GO TO 12
10 TS1=TWUS(ZZ,QR,K-1,PBP,PVAR,MARK)
TS2=TWUS(ZZ,QR,K,PBP,PVAR,MARK)
MODMST=(TS2-TS1)/C
C--- NOTE. MODMST WILL BE NEGATIVE
MSRT=TWUS(ZZ,QR,K,PBP,PVAR,MARK)/D
12 MSRTD=91.*MSRT
IF(MSRTD.LT.0.01)STOP=1
RETURN
END

C
C --- ROUTINE TO SEE IF GOAL HAS BEEN ATTAINED.
SUBROUTINE GOALM(X,N,Z,D,QR,TRY,MSRTG,PBP,PVAR)
INTEGER N,X(N),XI,PBP(N)
REAL Z(N),VO(1500),TV,SLT,D(N),QR(N),MSRTG,TRY

```

```

REAL MSRTC,MSRT,PVAR(N)
TV=0.0
SLT=0.
DO 10 I=1,N
  IF(Z(I).EQ.0.0)GO TO 16
  XI=X(I)
  SLT = SLT + D(I)
14  MSRTC=TWUS(Z(I),QR(I),XI,PBP(I),PVAR(I),MARK)/D(I)
  MSRT=AMAX1(MSRTC,0.0)
  GO TO 18
16  MSRT=0.0
18  VO(I) = 91.*MSRT
  TV = TV + VO(I)*D(I)
10 CONTINUE
  TV=TV/SLT
  TRY = 1.0
  IF(TV.LE.MSRTG)TRY = 0.0
22 RETURN
END

```

```

*
*VARIABLES NOT DEFINED IN PREVIOUS APPENDICES
*
*VARIABLE NAME  DATA
*NNN            (NOT USED)
*AMODEL         MODMST
*ZN             LEADTIME DEMAND
*QR             ECONOMIC ORDER QUANTITY
*STOP           1 OR 0 (INDICATES THAT THE ITEM HAS MET THE MSRT GOAL)
*GOALG          MSRT GOAL (EQUALS THE MSRT THE UICP MODEL COMPUTED FOR
*               THAT FOUR DIGIT COG
*
*MOD            (NOT USED)
*NN1           (NOT USED)
*ZZ            LEADTIME DEMAND
*C             UNIT PRICE
*K             INTERMEDIATE DEPTH
*TRY           1 OR 0 (INDICATES THAT THE FOUR DIGIT COG HAS MET THE
*               MSRT GOAL)

```

APPENDIX D. SUBROUTINE SHFLIF

```

SUBROUTINE SHFLIF(SL,SLC)
  REAL*4 A/'A' '/',B/'B' '/',C/'C' '/',D/'D' '/',E/'E' '/',
  *F/'F' '/',
  *G/'G' '/',H/'H' '/',J/'J' '/',K/'K' '/',L/'L' '/',M/'M' '/',
  *N/'N' '/',P/'P' '/',Q/'Q' '/',R/'R' '/',X/'X' '/',S/'S' '/',
  *A1/'1' '/',A2/'2' '/',A3/'3' '/',A4/'4' '/',A5/'5' '/',
  *A6/'6' '/',A7/'7' '/',A8/'8' '/',A9/'9' '/',A0/'0' '/'
  REAL*4 SL,SLC
  IF(SLC.EQ.A0)SL=100.
  IF(SLC.EQ.A0)GO TO 50
  IF(SLC.EQ.A)SL=1./3.
  IF(SLC.EQ.A)GO TO 50
  IF(SLC.EQ.B)SL=2./3.
  IF(SLC.EQ.B)GO TO 50
  IF(SLC.EQ.C.OR.SLC.EQ.A1)SL=3./3.
  IF(SLC.EQ.C.OR.SLC.EQ.A1)GO TO 50
  IF(SLC.EQ.D)SL=4./3.
  IF(SLC.EQ.D)GO TO 50
  IF(SLC.EQ.E)SL=5./3.
  IF(SLC.EQ.E)GO TO 50
  IF(SLC.EQ.F.OR.SLC.EQ.A2)SL=6./3.
  IF(SLC.EQ.F.OR.SLC.EQ.A2)GO TO 50
  IF(SLC.EQ.G.OR.SLC.EQ.A3)SL=9./3.
  IF(SLC.EQ.G.OR.SLC.EQ.A3)GO TO 50
  IF(SLC.EQ.H.OR.SLC.EQ.A4)SL=12./3.
  IF(SLC.EQ.H.OR.SLC.EQ.A4)GO TO 50
  IF(SLC.EQ.J)SL=15./3.
  IF(SLC.EQ.J)GO TO 50
  IF(SLC.EQ.K.OR.SLC.EQ.A5)SL=18./3.
  IF(SLC.EQ.K.OR.SLC.EQ.A5)GO TO 50
  IF(SLC.EQ.L)SL=21./3.
  IF(SLC.EQ.L)GO TO 50
  IF(SLC.EQ.M.OR.SLC.EQ.A6)SL=24./3.
  IF(SLC.EQ.M.OR.SLC.EQ.A6)GO TO 50
  IF(SLC.EQ.N)SL=27./3.
  IF(SLC.EQ.N)GO TO 50
  IF(SLC.EQ.P)SL=30./3.
  IF(SLC.EQ.P)GO TO 50
  IF(SLC.EQ.Q.OR.SLC.EQ.A7)SL=36./3.
  IF(SLC.EQ.Q.OR.SLC.EQ.A7)GO TO 50
  IF(SLC.EQ.R.OR.SLC.EQ.A8)SL=48./3.
  IF(SLC.EQ.R.OR.SLC.EQ.A8)GO TO 50
  IF(SLC.EQ.S.OR.SLC.EQ.A9)SL=60./3.
  IF(SLC.EQ.S.OR.SLC.EQ.A9)GO TO 50
  SL=100.
50 RETURN
END

```

☆

☆VARIABLE NOT DEFINED IN PREVIOUS APPENDICES

☆

*VARIABLE NAME	DATA
*SL	ITEM SHELF LIFE

APPENDIX E. REAL FUNCTION TWUS

```

C --- ROUTINE TO CALCULATE THE EXP TIME WTD UNITS SHORT FOR K UNITS
REAL FUNCTION TWUS(ZZ,QR,K,PBP,PVAR,MARK)
REAL ZZ,P1,P2,SW,RP,QR,P3,P4,P5,P6
REAL CCD1,CCD2,CCD3,CCD4,CCD5,CCD6,BETA1,BETA2
REAL*8 PHI1,PHI2,DCD1,DCD2,D1,D2,T1,T2,Z,DBETA1,DBETA2,S,R,PV
REAL*8 CD1,CD2,CD3,CD4,CD5,CD6
INTEGER K,MARK,PBP
SW=FLOAT(K)
S=SW
PV=PVAR
Z=ZZ
RP=SW-QR
R=RP
KRP=K-IFIX(QR+.5)
IF(ZZ.GE.FLOAT(PBP))GO TO 20
CALL CDFP(ZZ,KRP-1,P1,CD1,CCD1)
CALL CDFP(ZZ,KRP,P2,CD2,CCD2)
CALL CDFP(ZZ,KRP+1,P3,CD3,CCD3)
CALL CDFP(ZZ,K-1,P4,CD4,CCD4)
CALL CDFP(ZZ,K,P5,CD5,CCD5)
CALL CDFP(ZZ,K+1,P6,CD6,CCD6)
IF(CCD1.LT.0.000001)GO TO 10
BETA1=(CCD1*ZZ**2)/2.-CCD2*ZZ*KRP+CCD3*KRP*(KRP+1)/2.
IF(BETA1.LT.0.000001)BETA1=0.0
IF(CCD4.GE.0.000001)GO TO 7
BETA2=0.0
GO TO 8
7 BETA2=(CCD4*ZZ**2)/2.-CCD5*ZZ*K+CCD6*K*(K+1)/2.
IF(BETA2.LT.0.000001)BETA2=0.0
8 TWUS=(BETA1-BETA2)/QR
RETURN
10 TWUS=0.0
RETURN
20 T1=(R-Z)/DSQRT(PV)
IF(DABS(T1).LE.7.)GO TO 21
PHI1=0.0
IF(T1.GT.7.)D1=0.0
IF(T1.LT.(-7.0))D1=1.0
GO TO 22
21 PHI1=(DEXP(-(T1**2)/2.))/SQRT(2.*3.14159265)
CALL MDNORD(T1,CD1)
D1=1.0-CD1
* PRINT*,PV,D1,T1
* PRINT*,PHI1
22 DBETA1=PV*(D1*(1.0+T1**2)-T1*PHI1)/2.
T2=(S-Z)/DSQRT(PV)
IF(DABS(T2).LE.7.)GO TO 23
PHI2=0.0
IF(T2.GT.7.0)D2=0.0
IF(T2.LT.(-7.0))D2=1.0
GO TO 25

```

```

23 PHI2=(DEXP(-(T2**2)/2.))/SQRT(2.*3.14159265)
   CALL MDNORD(T2,CD2)
   D2=1.0-CD2
25 DBETA2=PV*(D2*(1.0+T2**2)-T2*PHI2)/2.
   TWUS=(DBETA1-DBETA2)/QR
   RETURN
   END

```

```

*
*ALL VARIABLES DEFINED IN PREVIOUS APPENDICES
*

```


APPENDIX F. SUBROUTINE ICPSMA

```

SUBROUTINE ICPSMA(N,COGG1,D,RF,DMAD,X,QQ,QMIN,Z,PBP,PVAR,H,RMAX,
*LAM,RMIN,MARK,SLC,PCLT,C1,E,
*MOD,QR,NSO,NRPR)
  INTEGER DEF,DEFR,ROP,ROPA,QA,QMIN(N),XE,ZI,Q2,X23,X24
  INTEGER XH,X2,X21,B019B,MARK(N),QS,Q21,Q2C,Y(1500),X(N),MOD
  INTEGER NSO(N),NRPR(N),PBP(N),ROPR(1500)
  CHARACTER*4 COGG1(N)
  REAL Z(N),DMAD(N),D(N),PVAR(N),PP(1500)
  REAL TWEB(1500),ETN(1500),RF(N),PCLT(N)
  REAL H
  REAL E(N),C1(N),SLC(N),QR(N),QQ(N),EF,EG
  REAL SIZ(1500),RMAX(N),RMIN(N),LAM(N)
  REAL*8 ZZ,PV,R,T1,PHI1,P1,CPHI1,USHRT1,WEB1,Q,T2,PHI2,P2,CPHI2
  REAL*8 USHRT2,WEB2,TR1,TR2,PHIR1,PHIR2,CPHIR1,CPHIR2,PR1,PR2
  REAL*8 EUS,ERUS3,ERUS4,REPQ
  DO 100 I=1,N
C *** COMPUTE REQUISITIONS SHORT FOR PROCUREMENT CYCLE, ETN
    ZZ=Z(I)
    PV=PVAR(I)
    ROP=X(I)-IFIX(QQ(I)+0.999)
    IF (D(I).EQ.0.0)THEN
      ETN(I)=0.0
      TWEB(I) = 0.0
      GO TO 100
    ENDIF
  3 IF(DMAD(I).NE.0.0)GO TO 5
    DMAD(I)=(1.39*D(I)**0.75)**2
    GO TO 5
  5 EF=1.57*DMAD(I)/(2.*D(I))
    W1=0.154
    EG=W1*D(I)*0.5
    DEF=IFIX(EF+EG+0.999)
    ROPA=ROP-DEF
    QA=IFIX(QQ(I)+0.5)+DEF
    XE=MAX0(QA,QMIN(I))
    Q=FLOAT(XE)
    IF(ROPA.GT.0)GO TO 10
    ZI=IFIX(Z(I)+0.999)
    KN=MIN0(ZI,XE)
    ETN(I)=(4.*RF(I)*FLOAT(KN))/FLOAT(XE)
    TWEB(I)=ETN(I)*(PCLT(I)+0.5*W1)/4.
    GO TO 100
  10 IF(Z(I).LT.FLOAT(PBP(I)))GO TO 20
    R=FLOAT(ROPA)
    T1=(R-ZZ)/DSQRT(PV)
    IF(DABS(T1).GT.7.)GO TO 11
    PHI1=(DEXP(-(T1**2)/2.))/SQRT(2.*3.14159265)
    CALL MDNORD(T1,P1)
    CPHI1=1.0 - P1
    GO TO 12
  11 IF(T1.GT.7.)CPHI1=0.0

```

```

      IF(T1.LT.(-7.))CPHI1=1.0
      PHI1=0.0
12  USHRT1=(DSQRT(PV))*(PHI1-T1*CPHI1)
      WEB1=PV*(CPHI1*(1.+T1**2)-T1*PHI1)
      T2=(R+Q-ZZ)/DSQRT(PV)
      AB=(R+Q)
      IF(DABS(T2).GT.7.)GO TO 13
      PHI2=(DEXP(-(T2**2)/2.))/SQRT(2.*3.14159265)
      CALL MDNORD(T2,P2)
      CPHI2=1.0 - P2
      GO TO 14
13  IF(T2.GT.7.)CPHI2=0.0
      IF(T2.LT.(-7.))CPHI2=1.0
      PHI2=0.0
14  USHRT2=(DSQRT(PV))*(PHI2-T2*CPHI2)
      WEB2=PV*(CPHI2*(1.+T2**2)-T2*PHI2)
      GO TO 50
20  BQ=PVAR(I)/Z(I)
      IF(BQ.GE.1.0.AND.BQ.LT.1.000001)BQ=1.000001
      BK=Z(I)/(BQ-1.0)
      PP(1)=1.0/(BQ**BK)
      USHRT1=Z(I)-FLOAT(ROPA)*(1.-PP(1))
      WEB1=Z(I)**2+PVAR(I)-2.*Z(I)*FLOAT(ROPA)+((FLOAT(ROPA))**2)*(1.-
*PP(1))
      IF(ROPA.LE.1)GO TO 23
      KM1=ROPA-1
      DO 22 J=1,KM1
      PP(J+1)=((BK+J-1)/(J))*((BQ-1.)/BQ)*PP(J)
      USHRT1=USHRT1-FLOAT(J-ROPA)*PP(J+1)
22  WEB1=WEB1-(FLOAT(J-ROPA)**2)*PP(J+1)
23  KM2=ROPA+XE-1
      IF(KM2.LE.1)GO TO 50
      USHRT2=Z(I)-FLOAT(KM2+1)*(1.-PP(1))
      WEB2=Z(I)**2+PVAR(I)-2.*Z(I)*FLOAT(KM2+1)+((FLOAT(KM2+1))**2)*(1.-
*PP(1))
      DO 24 J=1,KM2
      PP(J+1)=((BK+J-1)/(J))*((BQ-1.)/BQ)*PP(J)
      USHRT2=USHRT2-(FLOAT(J-KM2-1))*PP(J+1)
24  WEB2=WEB2-((FLOAT(J-KM2-1))**2)*PP(J+1)
50  EUS=DMIN1((USHRT1-USHRT2),Q)
      ETN(I)=EUS*4.*RF(I)/Q
      EW=(WEB1-WEB2)*RF(I)/D(I)
      TWEB(I)=EW/(2.*Q)
100 CONTINUE
C *** COMPUTE AGGREGATE SMA
101 SUMET=0.0
      SUMTWB=0.0
      SUMRF=0.0
      DO 102 I=1,N
      SUMET=SUMET+ETN(I)
      SUMTWB=SUMTWB+TWEB(I)
102 SUMRF=SUMRF+RF(I)
      SMA2=1-(SUMET)/(4.*SUMRF)
C *** COMPUTE AVERAGE DAYS DELAY
      ADDA2=365.*(SUMTWB)/(4.*SUMRF)
C *** COMPUTE ADD FOR BACKORDERS

```

```

ADDBO2=ADDA2/(1.-SMA2)
SMA2=SMA2*100.0
PRINT*
WRITE(6,149)
149 FORMAT('0',3X,'CARES REQUISITION-BASED PERFORMANCE MEASURES:')
WRITE(6,150)SMA2,ADDA2,ADDBO2
150 FORMAT('0',5X,'SMA=',F8.4,5X,'ADD=',F8.4,5X,'ADDBO=',F10.4)
DO 170 I=1,N
IF(RF(I).EQ.0.0)RF(I)=1.0
SIZ(I)=D(I)/RF(I)
ETN(I)=ETN(I)*SIZ(I)
TWEB(I)=TWEB(I)*SIZ(I)
170 CONTINUE
SUMET=0.0
SUMTWB=0.0
SUMRD=0.0
DO 180 I=1,N
SUMET=SUMET+ETN(I)
SUMTWB=SUMTWB+TWEB(I)
180 SUMRD=SUMRD+D(I)
SMA2=1-(SUMET)/(4.*SUMRD)
C *** COMPUTE AVERAGE DAYS DELAY
ADDA2=365.*(SUMTWB)/(4.*SUMRD)
C *** COMPUTE ADD FOR BACKORDERS
ADDBO2=ADDA2/(1.-SMA2)
PRINT*
SMA2=SMA2*100.0
WRITE(6,190)
190 FORMAT('0',3X,'DEMAND-BASED PERFORMANCE MEASURES:')
WRITE(6,150)SMA2,ADDA2,ADDBO2
WRITE(6,194)
194 FORMAT('0',1,'*****',
*'*****',
*'*****')
RETURN
*
*VARIABLES NOT DEFINED IN PREVIOUS APPENDICES
*
*VARIABLE NAME    DATA
*COGG1            1H
*QQ               REORDER QUANTITY
*
END

```

APPENDIX G. SUBROUTINES - PRTOU, OBJECT AND EBO

*THE FOLLOWING THREE SUBPROGRAMS WERE LISTED TOGETHER BECAUSE

*FUNCTION TOGETHER

**

C --- ROUTINE TO PRINT OUT RESULTS

```

SUBROUTINE PRTOU(MD,NAME,QM,B,Q,QRR,QR,NT,N,NN,X,Z,C11,D,MSRTG,
*COG1,COG2,NPO,TOV,QMR,PBP,PVAR,SLD,PCLT,NNN,NN1)
INTEGER ROP(1500),NPO,NT,KQ(1500),KQR(1500),KQW(1500),X(1500)
INTEGER PBP(N)
REAL Z(N),OV(2,1500),TOV(2),C11(N),MSRTG,BSW(1500),SLD
REAL Q(N),D(N),QRR(N),QR(N),PVAR(N)
REAL PCLT(N)
REAL*8 B
CHARACTER*23 NAME
CHARACTER*4 COG1(N),COG2(N),QM,QMR
COMMON SN(1500,9)
DO 1 I=1,N
  KQ(I)=IFIX(Q(I))
  ROP(I)=X(I)-KQ(I)
  BSW(I) = C11(I)*X(I)
1 CONTINUE
CALL OBJECT(X,N,NN,Z,D,QR,PBP,PVAR,OV,TOV)
WRITE(6,900)
900 FORMAT('1',///,' *****',
* ' *****',
* ' *****')
WRITE(6,901)MD,NAME,COG1(1),COG2(1),MSRTG,QM,N,NT,NNN
901 FORMAT('0',1X,MODEL('11,')',1X,A23,1X,'COG:',2A2,3X,
*'MSRT GOAL:',F8.2,' DAYS',3X,QP:',A4,3X,'NI/N:',I4,
*'/',I4,3X,'LOWER BD CODE:',I2)
IF(NPO.EQ.1)GO TO 907
WRITE(6,902)
902 FORMAT('0',5X,'NIIN',4X,'DEPTH',3X,'MSRT(DAYS)',2X,
*'INVEST. LVL.',5X,'C11($)',2X,'Q ',3X,'ROP',
*5X,'PPV',8X,'D',5X,'PCLT',
*5X,'PVAR')
WRITE(6,903)((SN(I,J),J=1,9),X(I),OV(2,I),BSW(I),C11(I),KQ(I),
*ROP(I),Z(I),D(I),PCLT(I),PVAR(I),I=1,N)
903 FORMAT(3X,9A1,2X,I5,2X,F10.4,1X,F13.0,1X,F11.2,I5,I5,
*F10.3,F8.3,1X,2X,F5.2,F9.1)
906 WRITE(6,904)TOV(2),B,TOV(1),SLD
904 FORMAT('0',2X,'TOTAL PERFORMANCE:',F9.3,1X,'$',F12.0,5X,
*'SMA:',F8.2,4X,'SAFETY LEVEL DAYS:',F8.2)
GO TO 909
907 WRITE(6,908)TOV(2),B,TOV(1),SLD
908 FORMAT('0',4X,'OVERALL PERFORMANCE:',2X,F9.3,4X,'$',F12.2,5X,
*'SMA:',F8.2,4X,'SAFETY LEVEL DAYS:',F8.2)
909 RETURN
END

```

**

* --- ROUTINE TO COMPUTE THE OBJECTIVE FUNCTIONS FOR GIVEN ALLOCATION
 SUBROUTINE OBJECT(X,N,NN,Z,D,QR,PBP,PVAR,OV,TOV)

```

INTEGER N,NN,X(N),XI,PBP(N)
REAL Z(N),OV(NN,N),TOV(NN),SLT,MSRT,OV1,D(N),QR(N)
REAL CD,P,MSRTC,BO,BOT,DD,PVAR(N)
TOV(1)=0.
TOV(2)=0.
BO=0.0
BOT=0.0
5 CONTINUE
SLT=0.
DO 10 I=1,N
    IF(Z(I).EQ.0.0)GO TO 16
    XI=X(I)
    SLT = SLT + D(I)
    OV(1,I)=0.
    CALL EBO(Z(I),XI,D(I),QR(I),OV1,PBP(I),PVAR(I))
    MSRTC=TWUS(Z(I),QR(I),XI,PBP(I),PVAR(I),MARK)/D(I)
    MSRT=AMAX1(MSRTC,0.0)
    OV(1,I)=AMIN1(OV1,1.0)
    GO TO 18
16    OV(1,I)=0.0
    MSRT=1.0
18    OV(2,I) = 91.*MSRT
    TOV(2) = TOV(2) + OV(2,I)*D(I)
    BO=BO+OV(1,I)
10 CONTINUE
    IF(SLT.EQ.0.0)SLT=1.0
    BOT=BO/SLT
    TOV(1)= (1.-BOT)*100.
    TOV(2)=TOV(2)/SLT
    RETURN
END

*
*
SUBROUTINE EBO(Z,X,D,QR,OV1,PBP,PVAR)
REAL Z,D,QR,OV1,ALPHA1,ALPHA2,X1,X2,D1,D2,P1,P2,PVAR
REAL*8 T1,T2,PHI1,PHI2,CDD1,CDD2,DD1,DD2,DLPHA1,DLPHA2,PV,CD1,CD2
INTEGER PBP,X
K1=X-IFIX(QR+.05)
X1=FLOAT(K1)
X2=FLOAT(X)
K2=X
PV=PVAR
IF(Z.GT.FLOAT(PBP))GO TO 10
CALL CDFP(Z,K1,P1,CD1,D1)
CALL CDFP(Z,K2,P2,CD2,D2)
ALPHA1=D1*(Z-X1)+X1*P1
ALPHA2=D2*(Z-X2)+X2*P2
IF(ALPHA1.LT.0.0)ALPHA1=0.0
IF(ALPHA2.LT.0.0)ALPHA2=0.0
OV1=(ALPHA1-ALPHA2)*D/1
GO TO 20
10 T1=(X1-Z)/DSQRT(PV)
IF(DABS(T1).GT.7.0)GO TO 12
PHI1=(DEXP(-(T1**2)/2.))/SQRT(2.*3.14159265)
CALL MDNORD(T1,CDD1)
DD1=1.0-CDD1

```

```

GO TO 13
12 IF(T1.GT.7.0)DD1=0.0
   IF(T1.LT.(-7.0))DD1=1.0
   PHI1=0.0
13 T2=(X2-Z)/DSQRT(PV)
   IF(DABS(T2).GT.7.0)GO TO 14
   PHI2=(DEXP(-(T2**2)/2.))/SQRT(2.*3.14159265)
   CALL MDNORD(T2,CDD2)
   DD2=1.0-CDD2
   GO TO 15
14 IF(T2.GT.7.0)DD2=0.0
   IF(T2.LT.(-7.0))DD2=1.0
   PHI2=0.0
15 DLPHA1=(PHI1-T1*DD1)*(DSQRT(PV))
   DLPHA2=(PHI2-T2*DD2)*(DSQRT(PV))
   IF(DLPHA1.LT.0.0)DLPHA1=0.0
   IF(DLPHA2.LT.0.0)DLPHA2=0.0
   OV1=(DLPHA1-DLPHA2)*D/QR
20 RETURN
END

```

*

*VARIABLES NOT DEFINED IN PREVIOUS APPENDICES

*

*VARIABLE NAME	DATA
*MD	1
*NAME	UICP CONSUMABLES MODEL
*QM	(NOT USED)
*QRR	(NOT USED)
*NT	1500 (LIMIT ON THE NUMBER OF ITEMS THE PROGRAM WILL PROCESS
*	
*NN	2 (NUMBER OF MEASURES OF PERFORMANCE - SMA & MSRT)
*NPO	1 OR 0 - PRINTOUT OPTION (1=SUMMARY, 0=FULL PRINTOUT)
*TOV	COMPUTED SMA AND MSRT
*QMR	(NOT USED)
*SLD	DAYS OF SAFETY LEVEL FOR THE ENTIRE FOUR DIGIT COG
*OV	MSRT FOR EACH NIIN
*OV1	EXPECTED NUMBER OF BACKORDERS

*

APPENDIX H. SUBROUTINE CDFP

```

SUBROUTINE CDFP(ZZ,K,P,C,D)
C --- ROUTINE TO CALCULATE POISSON CDF AND MASS
C --- CUMULATIVE POISSON DISTRIBUTION
REAL*8 ZZZ,PP,CC,CC1,DD,C
REAL ZZ,P,D
INTEGER K,I
IF(K.LT.0)GO TO 12
ZZZ=ZZ
PP=DEXP(-ZZZ)
CC=PP
CC1=0.0
IF(K.EQ.0) GO TO 11
KK=5*IFIX(ZZ+0.5)
IF(ZZ.GT.10.0.AND.K.GT.KK)GO TO 15
DO 10 I=1,K
CC1=CC
PP=PP*ZZZ/DBLE(I)
CC=CC+PP
10 CONTINUE
11 P=PP
C=CC
DD=1.0-CC1
D=DD
RETURN
12 P=0.0
C=0.0
D=1.0
RETURN
15 P=0.0
C=1.0
D=0.0
RETURN
END

C
SUBROUTINE CDFB(ZZ,K,PVAR,C,NB)
C --- ROUTINE TO CALCULATE NEGBINOMIAL CDF
REAL ZZ,C,PVAR
REAL*8 ZZZ,PP,CC,BR,R,BK,S22,B,BQ
INTEGER K,I,NB
NB=0
ZZZ=ZZ
S22=PVAR
BR=ZZZ/S22
BQ=S22/ZZZ
IF(BQ.LE.1.0)GO TO 8
R = 1.0-BR
BK=(ZZZ**2)/(S22-ZZZ)
IF(BK*DLOG(BQ).GT.9.0)GO TO 8
PP=BR**BK
CC=PP
IF(K.EQ.0) GO TO 11

```

```

      GO TO 9
8  NB=1
   RETURN
9  DO 10 I=1,K
      B=DBLE(I-1)
      PP=PP*R*(B+BK)/DBLE(I)
      CC=CC+PP
10 CONTINUE
11 C=CC
   RETURN
   END
*
```

*ALL VARIABLES EXCEPT OUTPUT VARIABLES (P, NB) PREVIOUSLY DEFINED

*

APPENDIX I. SAMPLE CHURN

Table 13. SAMPLE CHURN

COG IH3F		COG IH0A		COG IH4F		COG IH0D	
FREQ.	CHURN	FREQ.	CHURN	FREQ.	CHURN	FREQ.	CHURN
1	-1894		-10406		-515		-7217
	-980		-5523		-508		-8054
	-845		-2443		-385		-3393
	-840		-692		-290		-3222
	-460		-664		-269		-3183
	-445		-490		-133		-3104
	-400		-486		-81		-376
	-318		-441		-127		12
	-313		-408		-92		32
	-278		-370	2	-88		64
	-268		-355		-61		146
	-249		-330	2	-59		
	-220		-303		-57		
2	-195		-290	2	-56		
	-175		-285	2	-52		
	-168		-264		-51		
	-167		-262		-40		
	-154		-260	2	-38		
	-151		-234		-37		
	-140		-184		-36		
2	-136		-162		-35		
	-134		-159	2	-31		
	-125		-137		-28		
	-120		-133		-26		
	-114		-128		-25		
	-109		-93	4	-24		
3	-96	2	-75	3	-23		
	-93		-72	2	-22		
	-92	2	-50	2	-21		
	-88		-48	2	-20		
	-86		-17		-19		
3	-78		-15	2	-18		
	-77		-14	2	-17		
	-75		-11	2	-16		
	-71		-35	2	-15		
	-72		-39	4	-14		
	-66		-25	7	-13		
2	-65	2	-25	5	-12		
	-64		-18	5	-11		
	-63		-10	7	-10		
	-58		-6	6	-9		
2	-56		-2	14	-8		
1	-53		-2	22	-7		
	-49	2	0	23	-6		
2	-48		-2	23	-5		
	-47		-2	45	-4		
	-44		4	62	-3		
	-43	2	2	74	-2		
3	-40	3	6	90	-1		
2	-38	1	7	254	0		

Table 14. SAMPLE CHURN (CONTINUED)

LIST OF REFERENCES

1. Naval Postgraduate School Report No. NPS55-83-026, *Wholesale Provisioning Models: Model Development*, by F. R. Richards and A. W. McMasters, September 1983.
2. Naval Postgraduate School Report No. NPS55-86-011, *Wholesale Provisioning Models: Model Evaluation*, by Alan W. McMasters, May 1986.
3. Gormly, Richard B., *Analysis of an Aggregate Demand Repairables Model*, Master's Thesis, Naval Postgraduate School, Monterey, California, December 1985.
4. Hadley, G. and Whitin, T. M., *Analysis of Inventory Systems*, Prentice-Hall, 1963.
5. Apple, C. L., *A Systems Approach to Inventory Management of Repairables in the Navy*, Master's Thesis, Naval Postgraduate School, Monterey, California, March 1985.
6. Naval Supply Systems Command, *Inventory Management - A Basic Guide to Requirements Determination in the Navy*, NAVSUP Publication 553, 1988.
7. Tersine, R. J., *Principles of Inventory and Materials Management*, Elsevier Science Publishers, 1988.
8. Lippert, Keith W., *An Analysis of the Ships Parts Control Center Inventory Model and a Possible Alternative Model*, Master's Thesis, Naval Postgraduate School, Monterey, California, June 1977.
9. Fleet Material Support Office, *Application D, Operation 56 - CARES (Computational and Research Evaluation System) III*, FMSO Publication, 1984.

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